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LAKE MICHIGAN INTAKES: REPORT ON THE BEST TECHNOLOGY AVAILABLE

Lake Michigan Cooling Water Intake Technical Committee

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The Lake Michigan Cooling Water Intake Technical Committee concluded from its study of Lake Michigan intakes that in view of the wide range of ecological situations encountered when siting Lake Michigan intakes, no generic type intake structure or system can be recommended. However, it is essential that a systematic approach be used in evaluating each site. Current intake structure technology limits the minimization of environmental damage to the protection of adult and immature fish, important to Lake Michigan. Intake siting is the most important factor in avoiding intake problems. Site determination and intake design, including flow velocity and mechanical equipment considerations, should be preceded by a monitoring program.

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Lake Michigan Intakes: Report
on the Best Technology Available

By:

LAKE MICHIGAN

COOLING WATER INTAKE TECHNICAL COMMITTEE

August 1973

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SUMMARY

In view of the wide range of ecological situations which may be encountered when siting Lake Michigan intakes, it is evident that no generic type intake structure or system can be recommended. Each proposed and existing intake should be considered independently in arriving at the best technology for protecting aquatic life. However, it is essential that a systematic approach be used in evaluating each site. Listed below are several key elements which are discussed in detail in the report and should be incorporated in this approach:

1. The single most important factor in avoiding intake problems is through the careful consideration of the location of the intake.
2. Current intake structure technology limits the minimization of environmental damage to the protection of adult and immature fish, important to Lake Michigan.
3. The adequacy of existing intake facilities must be determined by a monitoring program which measures the daily and seasonal variations in numbers, size and weight of all life stages of the fish species entrapped in the intake system.
4. A monitoring program must be conducted prior to locating and designing new intake facilities to avoid areas where fish concentrate.
5. The intake structure should not serve as an attractant to immature and adult fish either by physical alteration of the

environment, by providing shelter or by the influence of heated discharge water, unless deicing is essential for maintenance of water flow.

6. In the absence of other adequate fish-protection devices, intake water velocities should not exceed the escape velocities of the fish of concern. Some of the studies reviewed indicated that velocities of 0.5 feet per second or two to three times the body length of the fish per second, whichever is greater, would be adequate to protect the designated species and life stages.
7. Fish should be returned undamaged from the forebay area to a physical environment which approximates that at the point of withdrawal through the utilization of a well designed return system.
8. Horizontal traveling screens and louver screens, although in experimental stages, appear to have the greatest potential as fish-protection devices where fish bypasses are required.
9. There is a need for a cooperative effort by State and Federal governments and private industry to learn more about the aquatic life in Lake Michigan, as well as intake technology and design required to minimize entrainment and entrapment of all aquatic organisms.

10. Federal and State government, private facilities and private industry must combine efforts to:
    a. bring the current construction of intakes up to date with known and accepted technology;
    b. maintain open channels of communication which would evaluate national innovations in the technology;
    c. sponsor bold and innovative research on intake methods for Lake Michigan;
    d. locate and map areas of concentration of the aquatic organisms of Lake Michigan which may be affected by the use of its waters.

I. INTRODUCTION

The problem of adverse environmental effects resulting from the entrainment, entrapment and destruction of aquatic biota by cooling water users on Lake Michigan was discussed during past Lake Michigan Enforcement Conferences (LMEC) (January 1968, February 1969, March 1970, September 1970, March 1971, September 1972). However, little, if any, action has been taken to protect aquatic life by way of location, design and operation of intake structures. Principal concerns in past intake designs have been to obtain the quantity and quality of water desired and protection of aquatic life has been coincidental to the protection of equipment.

During the November 9, 1972 Public Session of the last LMEC (Appendix A), the problems were again recognized and the Conferees agreed to the establishment of a "Cooling Water Intake Technical Committee" to prepare a report on the "best intake technology available" for Lake Michigan. The mandate was to evaluate existing data and to make appropriate recommendations to the United States Environmental Protection Agency (U.S. EPA) and the Lake Michigan states. The mandate included a brief review of the 1972 Federal Water Quality Act (92-500) which states "Any standard established pursuant to section 301 or section 306 of this Act and applicable to a point source shall require that the location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact". This report represents the work of that Committee.

The Committee was made up of representatives from the U.S. EPA, United States Department of the Interior and the utilities and State agencies in the four States bordering Lake Michigan. For a listing of Committee members, participants, and report reviewers, refer to Appendix B.

Very early in the Committee deliberations, it was decided that the discussion of environmental problems resulting from withdrawing water from Lake Michigan should not be limited to power plant cooling waters because the environmental effects are similar regardless of the use. While information presented in this report is directed primarily towards cooling water intakes, it may also apply to industrial and municipal intakes.

The first objective was to delineate and define areas of the environment which might be affected by the placement, design and operation of intake structures. These areas of environmental concern are presented in Section II of the report. Section III of the report presents a review of water intake design technology currently in use and/or available for possible application to Lake Michigan. Recommended monitoring programs for existing and proposed facilities are outlined in Section IV. Finally, the Committee recognized many areas where additional knowledge is required for both environmental concerns and mechanical technology. Section V outlines those areas.

II. DEFINITION OF ENVIRONMENTAL CONCERN

Any loss of biological life caused by withdrawal of water from Lake Michigan constitutes an environmental concern until the significance of such loss is determined with respect to the aquatic ecosystem. Water users that create this concern are municipalities, industries, and electrical generating stations.

Appendix C contains a brief review of the biota that utilize the near-shore waters of Lake Michigan where most water intakes are located. Appendix C also discusses the results of some of the special studies and biological monitoring programs conducted by universities, government agencies (State and Federal) and industry. While Appendix C does not purport to be a comprehensive review of all the pertinent literature, it does demonstrate that biota in this area of the lake undergo seasonal and diurnal changes in abundance and are affected to various degrees when water is withdrawn.

Organisms found in the near-shore waters of Lake Michigan include phytoplankton, zooplankton, bottom fauna, and all size groups of fish from egg to adult. Plankton abundance (density/unit volume) is generally greater in near-shore than off-shore areas due in part to the higher nutrient concentrations in this area. The reverse is true for benthic populations which generally increase in density with distance from shore. The scouring action of waves in the littoral zone is probably the major factor responsible for low benthic populations in the shallow water areas. Fish abundance in the near-shore area is variable by location, season, species, and size.

Water intakes may entrain portions of all the previously mentioned biological communities. Once entrained in the intake water, most aquatic organisms will pass through the conventional screening systems. At generating stations these organisms undergo additional stress and mortality due to rapid temperature increases in the condensers before they are returned to the lake. Mechanical abrasion and pressure changes in the circulating water pumps and condenser tubes as well as biocide treatment of intake waters also contribute to mortality and sublethal effects to organisms passed through generating facilities. Mortalities which have been reported for the various aquatic communities range from 0 to 100% depending on size and species involved. The majority of organisms entrained in water withdrawn by industrial and municipal users suffer complete mortality because the water is not returned directly to the lake.

While there is much concern about the effects of entrainment on phytoplankton, zooplankton and benthic organisms, it was concluded by the committee that "best available technology" cannot adequately protect for these groups of organisms at present except through careful intake and site location. The importance of entrainment effects on these biota needs resolution, and this is under investigation as part of the responsibility of the Lake Michigan Cooling Water Studies Panel.

Adult and immature fish, drawn into the intake system but too large to pass through intake screens, are either removed by the screens or return to the lake the way they entered. Fish that are impinged on screens are lost to their respective populations through mortality. Fish larvae and young of the year that pass through these screens may undergo substantial mortality due to mechanical abrasion and pressure changes as well as temperature increases. Even though the loss of fish (important to both the sport and commercial fishery, and to the food chain) is of concern, it is recognized that the real concern is with population effects that:

1. reduce harvestable yields to sport or commercial fisheries or the food chain;
2. could lead to a general decline and demise of a species;
3. could result in changes of community structure.

For example, it can be reasonably predicted that some loss of alewives, because of their present population levels and documented reproductive success, will not affect their population and is therefore tolerable. In contract, the loss of ripe lake trout is intolerable in a documented spawning area because of lack of natural reproduction.

Prominent sport fishes in Lake Michigan are the salmonids which include lake trout, coho salmon, steelhead or rainbow trout, chinook salmon, and the brown and brook trout. Yellow perch are also important sport fish. Sport species important in northern Lake Michigan and in Green Bay, in addition to those already mentioned, are walleye, northern pike, and small-mouth bass. Fish currently most common in the diet of the above sport species are the alewive, smelt, and sculpin. Species important to the commercial fishery at the present time include bloater (chubs), whitefish, alewive, yellow perch, and smelt. Intake structures should be sited, designed, and operated for protection of life history stages important to maintenance of local and lake-wide populations of the above mentioned sport, commercial and forage fish.

It is expected that intake problems related to fish will vary among locations on the lake because of differences in distribution of fish populations and presence or absence of spawning and nursery areas. The committee believes that it is the responsibility of the electrical utilities and other water users to provide data collected in programs developed in cooperation with Federal, State, and local agencies to be used in the biological assessment of intake losses at each station or location. Decisions with respect to application of "best available technology" discussed in Section III should be the result of information gained from the monitoring and special studies discussed in Sections IV and V, respectively.

III. BEST TECHNOLOGY CURRENTLY AVAILABLE

A. General

The operation of existing water intake facilities was evaluated and the literature was reviewed to obtain information on the minimization of damage to the environment and the protection of fish. The exclusion of fish eggs and larvae at the intake depends at the present time almost wholly on the proper siting of the intake structure.

The design criteria and requirements contained herein are applicable to both existing and proposed intake structures in Lake Michigan waters.

1. For existing facilities, it is the responsibility of the operator to demonstrate that the design and operation of the existing structure has not caused nor can be expected to cause adverse environmental impact as defined in Section II.
2. New facilities should be located and designed in accord with criteria discussed throughout this section. The operator must demonstrate to appropriate Federal and State regulatory agencies that a design or combination of designs is the most effective for protection of fish life and other aquatic biota prior to actual operation.

B. Plant Siting and Intake Location

Plant siting and intake location are the two most important factors to minimize entrainment, entrapment and destruction of aquatic organisms. Since the distribution of aquatic biota in Lake Michigan is seldom random, potential plant sites should receive careful historical and empirical consideration to avoid fish spawning, nursery areas, and migratory routes. Such information is usually non-existant and even when available, it is often too general or archaic for application.

It is mandatory therefore, that plant siting and intake locations for all new plants on Lake Michigan be preceeded by pre-siting surveys. It cannot be overemphasized that protection of fish eggs and larvae is entirely dependent on siting and intake location. The following are suggested criteria for plant siting and intake location:

1. Intake structures should not be located in spawning areas, nursery grounds, migratory routes, or river mouths since these are areas which can be expected to have large concentrations of fish.
2. Intake structures should not be located in areas influenced by heated discharges because of the potential for attracting fish during the colder months of the year. It is recognized that it may be necessary to direct heated water to the intake for de-icing purposes. However, this practice cannot be accepted until adverse environmental effects are fully evaluated.
3. Intake structures located either inshore or offshore should be designed to minimize shelter and surface area

for attachment or attraction of biota which would counteract attempts to place the intake in an environmentally acceptable location.

4. It is desirable to permit withdrawal of water from various vertical depths in the water column to avoid the largest concentration of fish, eggs, and larvae which may change with time.

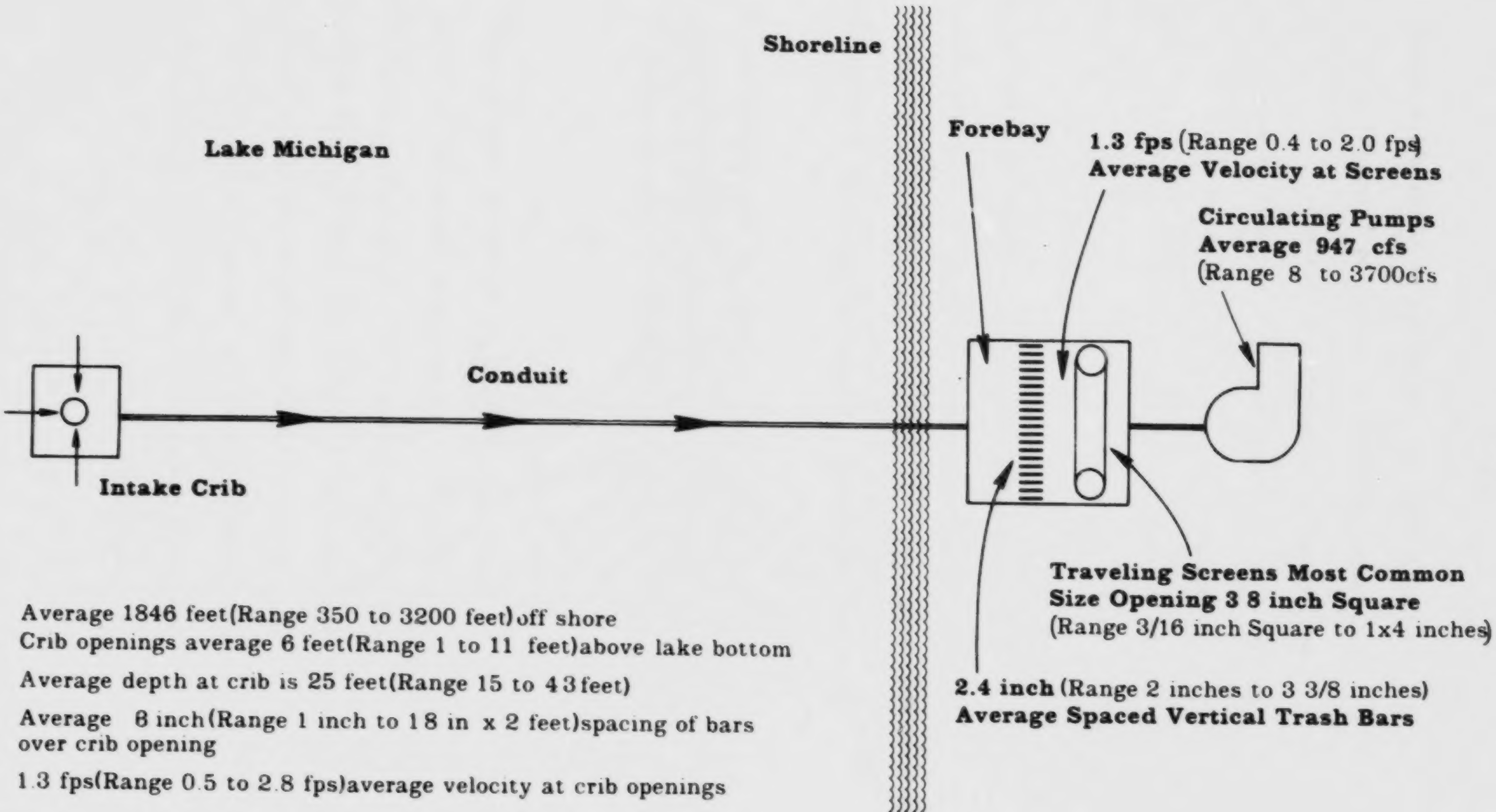
C. Intake Design

A questionnaire requesting pertinent data on intake designs, water flow characteristics and problem areas was distributed to all water users withdrawing water from Lake Michigan. Information obtained is summarized in Appendix D.

The following is a synthesis of the information in Appendix D along with information from the literature which applies primarily to electric generating facilities.

1. Offshore Intake

A closed conduit offshore intake is usually constructed without screening at the point of intake due to construction difficulties and clogging material. A generalized schematic for existing Lake Michigan power plant offshore cooling water intake systems is presented in Figure 1. Various intake crib designs which are presently in use in the lake are presented in Appendix D.


Lake Michigan
Shoreline
Forebay
1.3 fps (Range 0.4 to 2.0 fps)
Average Velocity at Screens
Circulating Pumps
Average 947 cfs
(Range 8 to 3700cfs
Conduit
Intake Crib
Traveling Screens Most Common
Size Opening 3 8 inch Square
(Range 3/16 inch Square to 1x4 inches)
2.4 inch (Range 2 inches to 3 3/8 inches)
Average Spaced Vertical Trash Bars

Average 1846 feet(Range 350 to 3200 feet)off shore
Crib openings average 6 feet(Range 1 to 11 feet)above lake bottom

Average depth at crib is 25 feet(Range 15 to 4 3 feet)

Average 8 inch(Range 1 inch to 1 8 in x 2 feet)spacing of bars over crib opening

1.3 fps(Range 0.5 to 2.8 fps)average velocity at crib openings

Figure 1 REPRESENTATIVE SCHEMATIC
OF AN EXISTING LAKE MICHIGAN POWER PLANT
COOLING WATER INTAKE SYSTEM

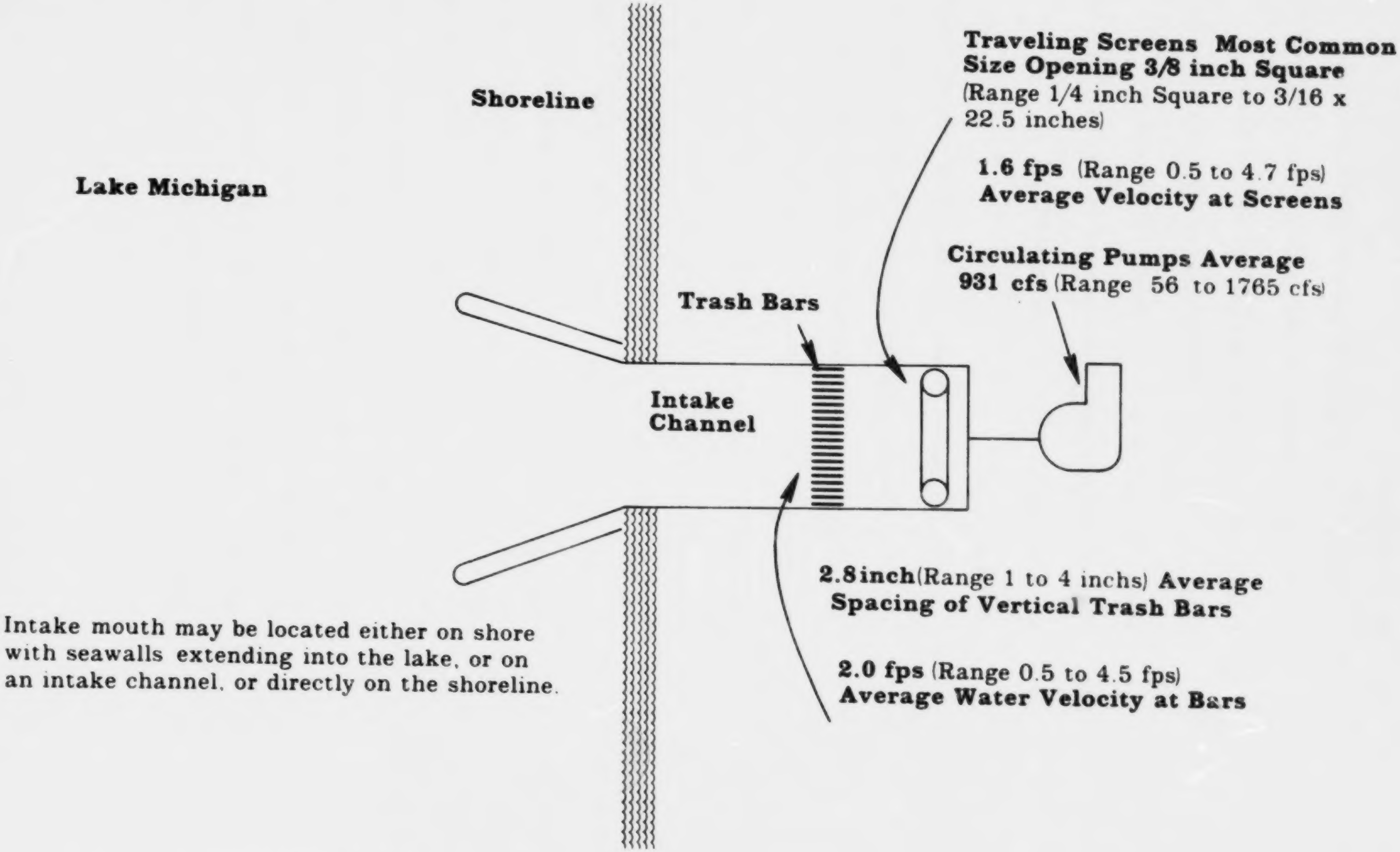
2. Shore Intakes

Shoreline intakes on Lake Michigan generally consist of a channel extending from the lake shoreline inland to the forebay or screening area. Typically lakeward jetties or ice barriers are installed to protect and maintain the channel. Figure 2 is a generalized schematic for existing Lake Michigan power plant shore intakes.

3. Forebay

At most power plants on Lake Michigan, a forebay and screenhouse area precede the condenser cooling water intake pumps. Screening devices, fish exclusion devices and chlorination equipment are generally located in this area. Between the forebay and pumps are located stationary coarse bar trash racks followed by movable fine screens which prevent debris and large fish from entering the system. Chlorine for biofouling control on heat exchange surfaces is generally added between the fine screens and pumps. Chlorine should never be added upstream of the fine mesh screens.

The forebay area can easily become a fish trap if water velocities exceed fish swimming speeds, barriers are present to prevent lateral movement of fish across screens, and no designed avenue for escape is available. None of the intake forebay combinations currently in



Traveling Screens Most Common Size Opening 3/8 inch Square (Range 1/4 inch Square to 3/16 x 22.5 inches)

1.6 fps (Range 0.5 to 4.7 fps) **Average Velocity at Screens**

Circulating Pumps Average 931 cfs (Range 56 to 1765 cfs)

2.8 inch (Range 1 to 4 inchs) **Average Spacing of Vertical Trash Bars**

2.0 fps (Range 0.5 to 4.5 fps) **Average Water Velocity at Bars**

Intake mouth may be located either on shore with seawalls extending into the lake, or on an intake channel, or directly on the shoreline.

Figure 2 REPRESENTATIVE SCHEMATIC OF AN EXISTING LAKE MICHIGAN POWER PLANT SHORELINE COOLING WATER INTAKE SYSTEM

in use on Lake Michigan employ more than token fish diversion or protection devices. (Appendix D). The few plants that have installed devices such as air bubble curtains or electrical fields have not quantatively evaluated their effectiveness for fish diversion. The following section reviews available technology that could be employed to prevent fish entrainment and entrapment.

D. Exclusion Devices

Fish exclusion devices may be separated into two basic groups: (1) those which provide physical barriers to fish passage, and (2) those which make use of fish behavioral responses to deflect or discourage their passage.

1. Physical Barriers

Various types of self-cleaning and fixed screens are presently available, and some of these are in operation on Lake Michigan at existing intake facilities, while others are still in the experimental stage. The general types are trash racks, vertical traveling screens, inclined plane screens, and fixed screens.

a. Trash Racks - These usually are flat steel bars placed vertical to flow, 1" to 6" apart, and protect the more delicate fine screens from damage due to large floating debris. (Figure 3). Debris removal is either manual or mechanical, and all debris removed from the face of the trash rack should be

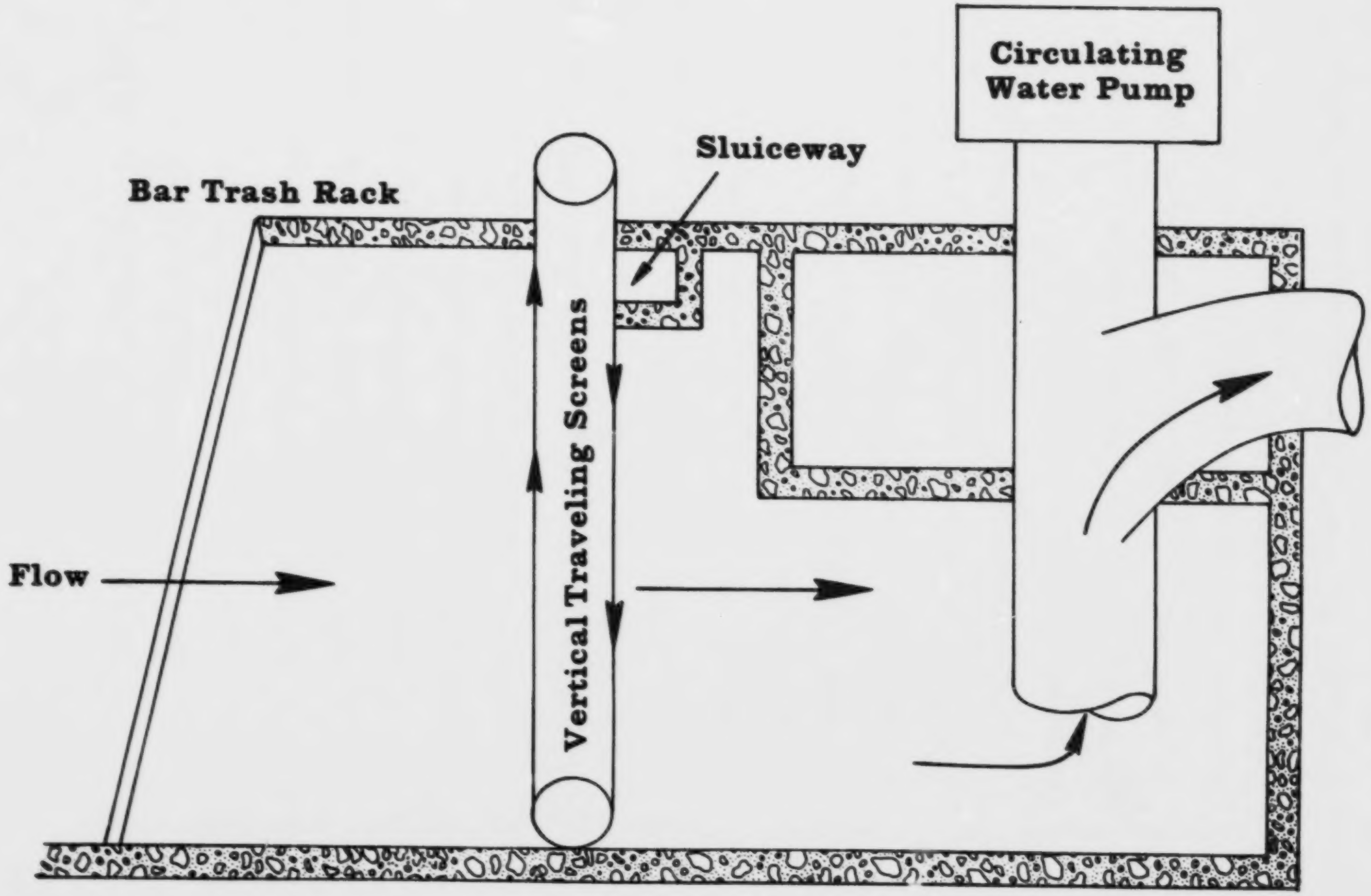

Circulating Water Pump
Sluiceway
Bar Trash Rack
Vertical Traveling Screens
Flow

Figure 3 REPRESENTATIVE LAKE MICHIGAN COOLING WATER INTAKE FOREBAY

disposed of on shore and not returned to the lake. Trash racks aligned at an angle of 20° to 30° to the incoming flow have proved effective both in the removal of heavy debris and in deflecting fish away from the fine screens.(40)

b. Vertical Traveling Screens - These screens placed normal to water flow are the most common screening devices in use at power plants utilizing Lake Michigan water. (Figure 3). The screens generally have 3/8" openings and are automatically activated, by timers or pressure differential, for cleaning. High velocity water jets are usually used to wash materials from the screens into a sluiceway. Fish removed in this manner invariably suffer high mortality. Screens and supporting structures should be angled and/or aligned to form a smooth face devoid of projections or pockets which could prevent lateral movement of fish to safe escape routes or removal areas.(21) It may be possible to install lifting troughs on these screens which would contain water and transport fish safely to bypass areas.

c. Horizontal Traveling Screens - The use of horizontal traveling screens is still in the experimental stage. However, testing with full scale models at West Coast sites suggests it is one of the most promising approaches available. The structure is designed to divert fish and debris into a bypass area. (Figure 4). When the horizontal screen is located at an angle, the flow velocities can be increased and fish impingement velocities are thereby decreased.(5),(39) Further study on the use of this method of screening is recommended.

d. Revolving Drum Screens - The revolving drum screen consists of a large perforated drum installed horizontally across the intake channel which forms a barrier to the passage of fish and debris. While turning, channels fixed to the drum lift impinged fish and debris clear of the water where they are washed into a collecting trough for disposal. Preliminary information indicates that the drum screen installation is simple and economical to operate and maintain. It is also possible to mount the drum screen on a vertical axis and to divert debris and fish to a special bypass structure.(21) (Figure 5).

e. Inclined Plane Screens - The inclined plane screen is actually a fixed screen inclined in a downstream direction. Cleaning is accomplished by bars or brushes which slide up the screen surface scraping debris or fish into a trough at the crest. Where the screen is being used to divert fish, a shallow

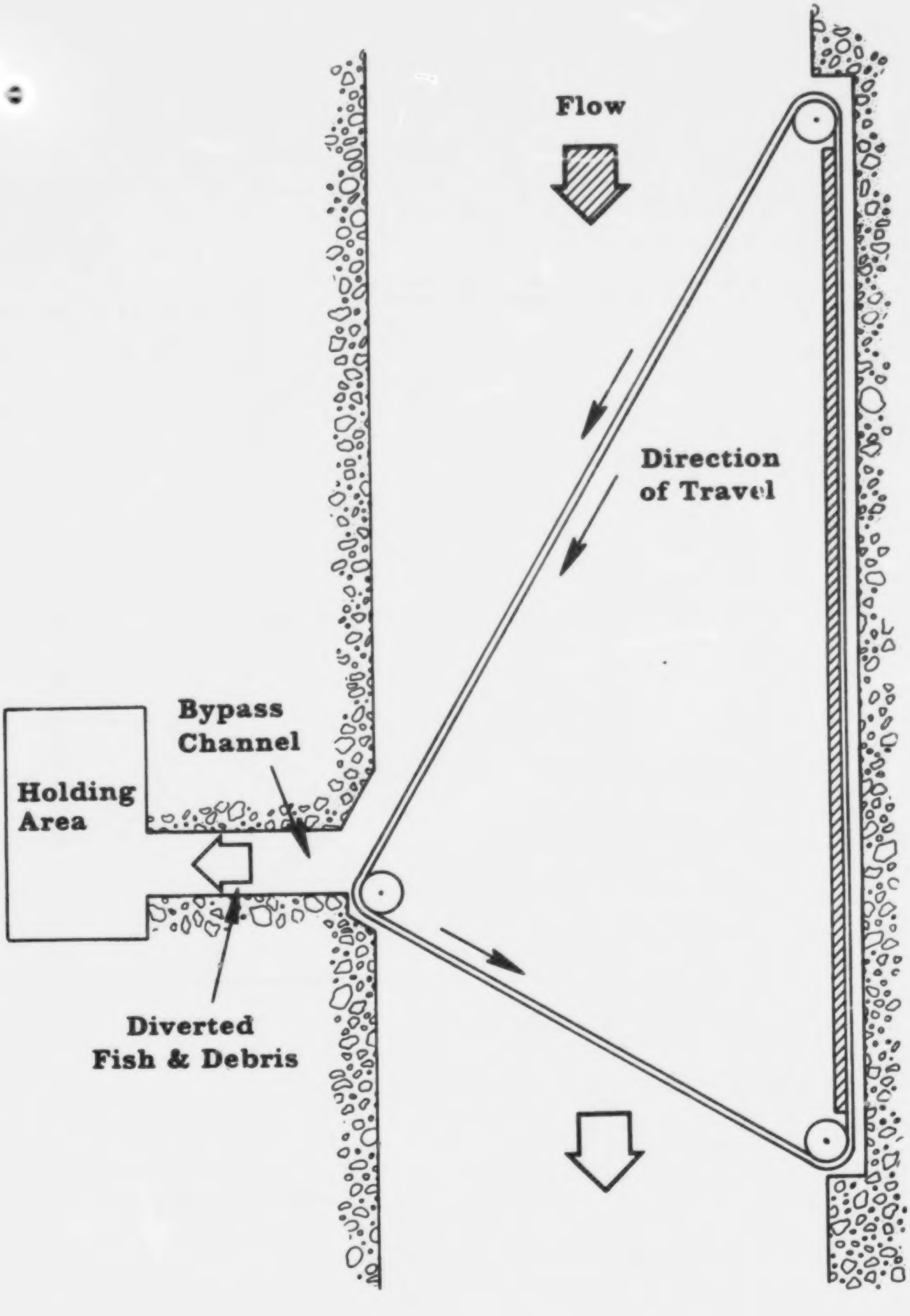

Flow
Direction of Travel
Bypass Channel
Holding Area
Diverted Fish & Debris

Figure 4 HORIZONTAL TRAVELING SCREEN

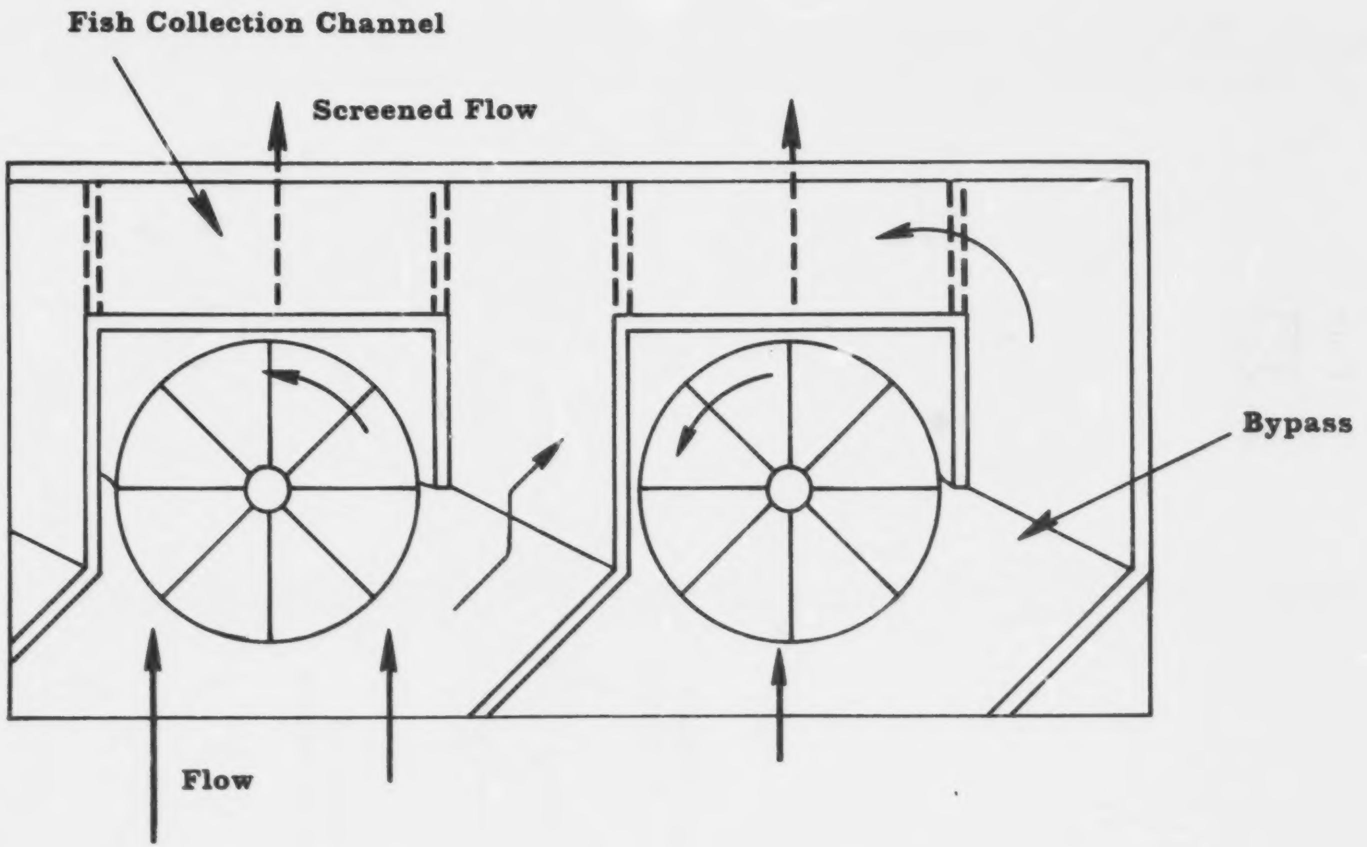

Fish Collection Channel
Screened Flow
Bypass
Flow

Figure 5 VERTICAL REVOLVING DRUM SCREEN

incline is used and the bars move fish through the shallows over the crest into the bypass trough(20) (Figure 6).

f. Fixed Screens - Simple fixed screens are the most economical method of screening where suspended debris is negligible. This can be anticipated for on-shore intakes in northern Lake Michigan or at some off-shore intakes. Where fish protection is necessary, use of these screens would require that they be angled or aligned to form a smooth face to allow for lateral movements of fish to bypass or removal areas.

g. Perforated Plate Screens - Vertical perforated plate screens diagonal to the flow have been tested but have not gained wide use. Studies have shown that average water velocities should be less than 0.25' per second to avoid problems with impingement.(13) It is anticipated that fish bypass channels would be required if this system is to be used.

2. Behavioral Barriers

Many types of barriers have been designed and installed which use fish behavior or reaction patterns to discourage fish from entering a given area. Some of these barriers cited in the literature are electric screens, sound screens, light screens, air bubbler systems, traveling cables and chains, odors and louver

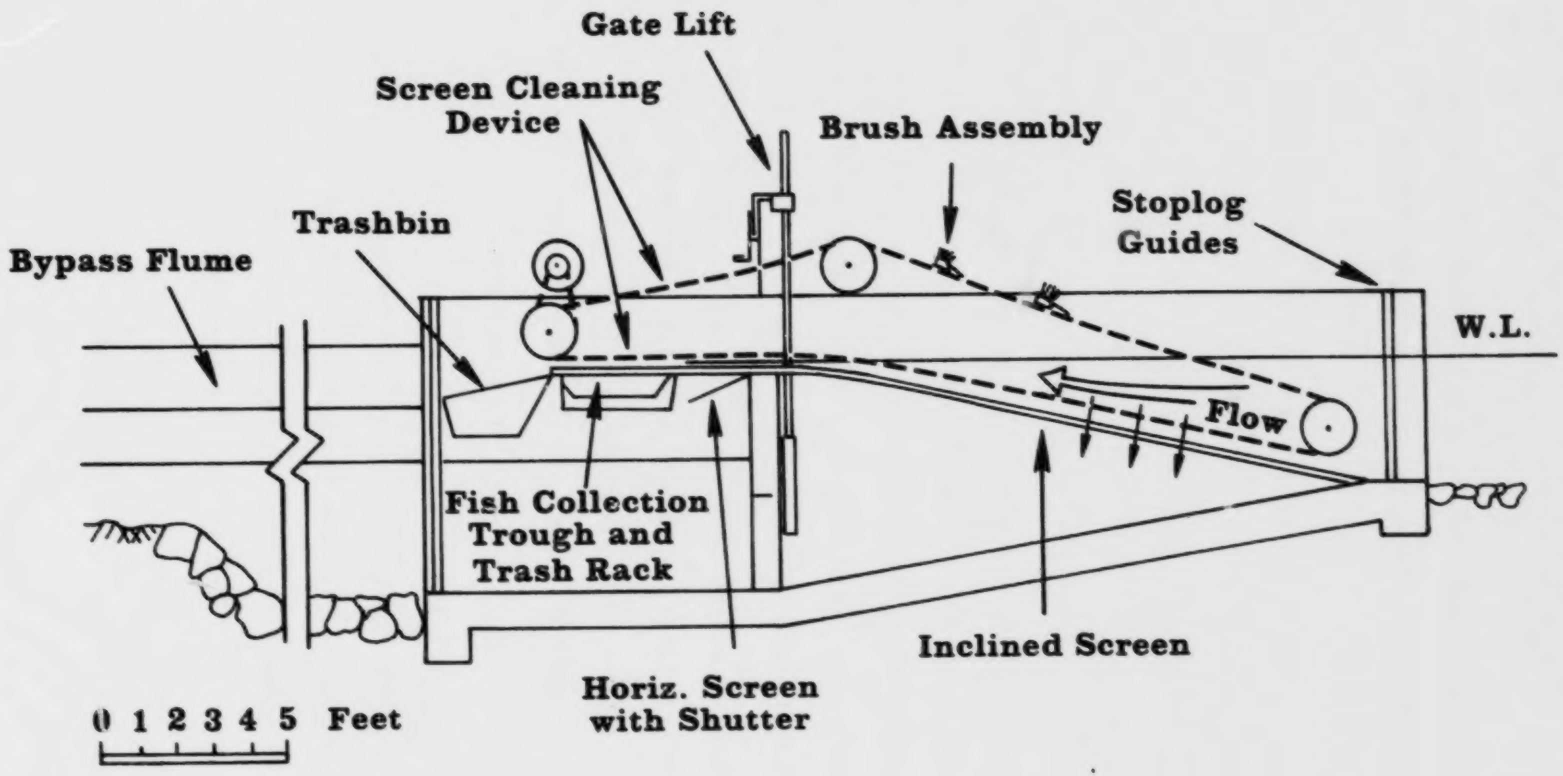

Gate Lift
Screen Cleaning Device
Brush Assembly
Stoplog Guides
Trashbin
Bypass Flume
W.L.
Flow
Fish Collection Trough and Trash Rack
Inclined Screen
Horiz. Screen with Shutter
0 1 2 3 4 5 Feet

Figure 6 INCLINED PLANE SCREEN

screens. The effectiveness of these barriers is variable depending on location, fish species, time of day, silt load, size of fish, and water temperature. In most cases, the behavioral barrier becomes ineffective when the fish are confronted by a higher priority stimulus, such as a predator and, therefore, it cannot be relied upon solely for fish protection.(10) Installation of these barriers can be readily accomplished and their use at facilities where fish entrapment problems presently exist may be adequate as a back-fitting technique to reduce losses to acceptable levels.

a. Electric Screens - Electric screens utilize current pulses to control or guide fish away from intake openings.(11) Electric screens have been used in Lake Michigan since 1940 on water intakes, however, their effectiveness has never been quantitatively evaluated, and until they have, these screens have limited application.(52)(23)

b. Sound Screens - Experimental work has been conducted on the use of sound waves to discourage fish passage. Preliminary reports indicate this method to be unreliable in its present state of development and the equipment necessary for even marginal results requires a large power source. (49),(35),(45)

c. Light Screens - The use of light to attract or repel fish has been tested at many installations. Generally, dim lights will attract fish and bright lights will repel them, depending upon fish species and time of year. It is deemed impracticable to use lights alone to form a behavior screen because of the lack of understanding of the fish reaction to lights. It is possible that there are some installations where the use of lights in conjunction with other types of screens will provide an effective barrier.(10)

d. Air Bubbler Screens - The air bubbler system has been evaluated at several water intakes, and has proved to be inconsistent in preventing fish passage. The effectiveness of this system varies with the type and size of fish. It has been useful in minimizing surface ice and possibly frazzle ice formations at some locations. The air bubbler system should not be used as the basic screening device for restraining fish passage into an intake system because of the highly variable efficiency, and because it is considered ineffective at night.(2),(8)

e. Traveling Cable and Chain Screens - Experiments have been conducted using lengths of hanging cables or chains to guide downstream migratory fish into a bypass. The effectiveness of the traveling cable screen has not been fully determined.(10)

f. Vertical and Horizontal Louver Screens - The louver screens can be designed for relatively high perpendicular approach velocities with the distance between vanes varying from 1" to 6" and placed at angles from 12° to 20° from the line of flow.(4),(42) The opening and the angle to the flow is dependent upon the swimming speed of the fish to be protected. The panels of the louvers should be aligned to insure smooth fish passage toward the bypass mouth.(27),(42) A bypass entrance velocity to channel approach velocity ratio of 1.2:1 to 1.5:1 is desirable.(18) This appears to be one of the most promising new methods and further study on application to Lake Michigan water intakes is warranted. (Figure 7). Debris affects the efficiency of this type of screen, and separate provisions for its removal are required.

E. Bypass and Fish Removal Systems

It is necessary to bypass the screening device and return the fish undamaged to a physical environment (water temperature, pressure, etc.) which approximates at the point of withdrawal.

1. Channel or Conduit Discharge. Channel or conduit discharges require significant volumes of water and a

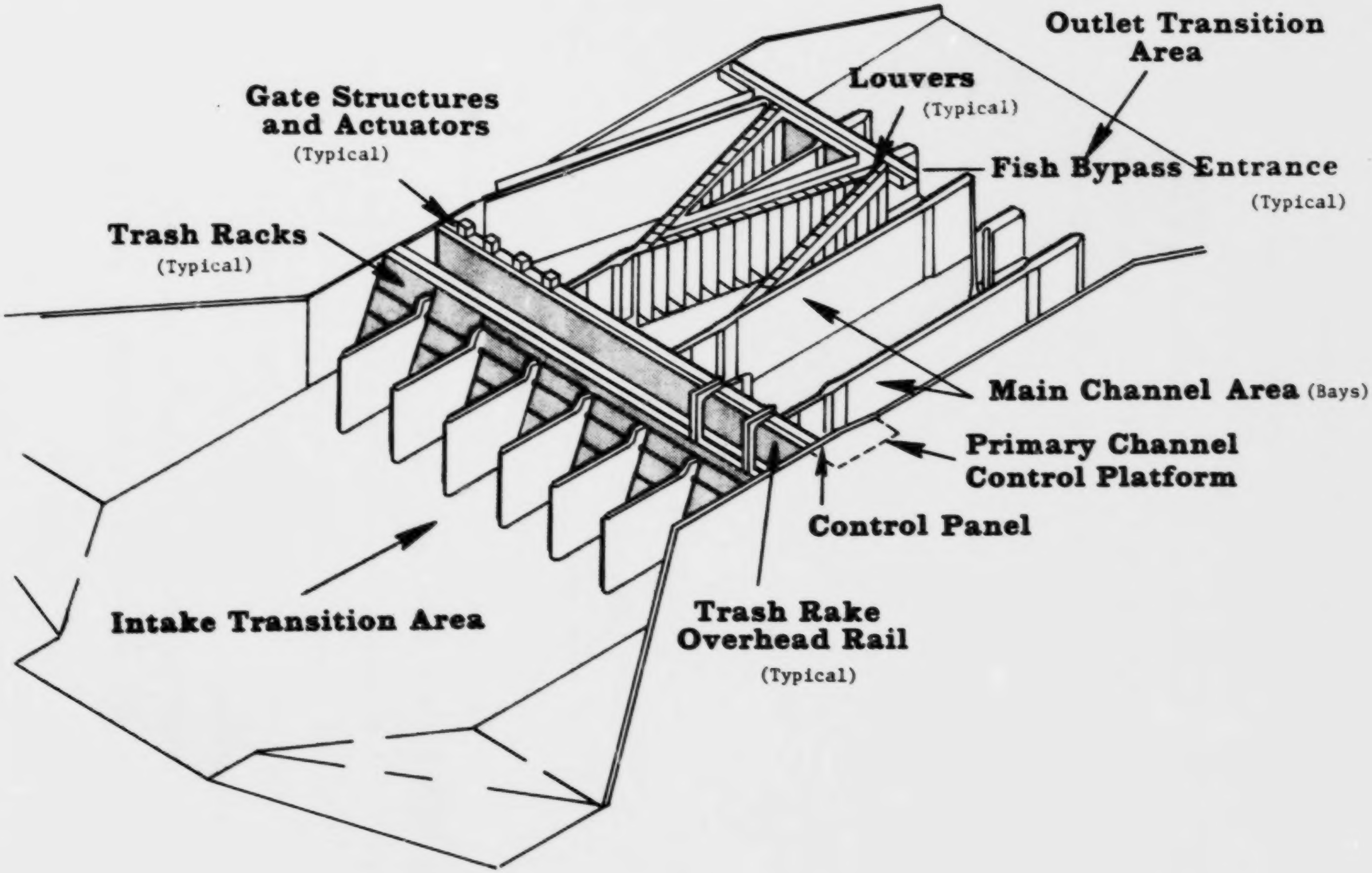

Outlet Transition Area
Louvers (Typical)
Gate Structures and Actuators (Typical)
Fish Bypass Entrance (Typical)
Trash Racks (Typical)
Main Channel Area (Bays)
Primary Channel Control Platform
Control Panel
Intake Transition Area
Trash Rake Overhead Rail (Typical)

Figure 7 LOUVER SCREEN
Delta Fish Facility Primary Channel System.
(From California Dept. of Water Resources Manual OM-201)

a receiving water at lower elevations than the source. The temperature difference between intake and discharge waters at power plants precludes use of the discharge as a conduit.

2. Pumps. Volute (fruit pumps) and diaphram pumps have been used to bypass fish from fish intake screen areas back to the waters from which they were diverted, however, injury and mortality can be a serious problem.(16),(36),(41) The use of a screw pump (Figure 8) on the bypass system should be explored more fully as a means of preventing pump damage to fish.
3. Elevator. Bypass channels can be equipped with basket elevators to lift fish from the intake back to the water.(16)
4. Fish Crowders. It is necessary to equip most screens constructed perpendicular to the water flow with a physical or behavioral guidance system to crowd fish to a bypass channel or elevator for removal and subsequent return to the water.(29)

F. Infiltration Systems

The use of collector wells (Raney method) or infiltration galleries is a means of preventing the entrapment of fish, fish eggs and fish larvae. In the collector well system, a caisson is sunk into water bearing sand or gravel in or adjacent to the lake. (Figure 9) The bottom of the caisson is plugged and

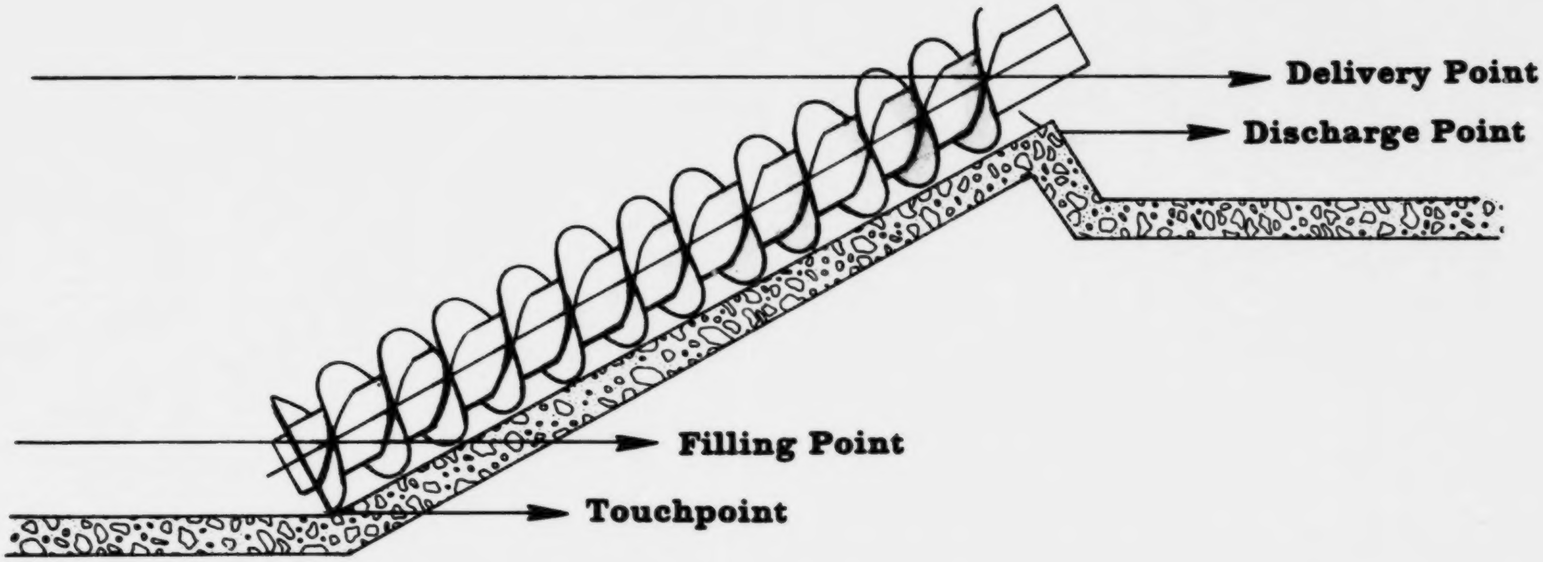
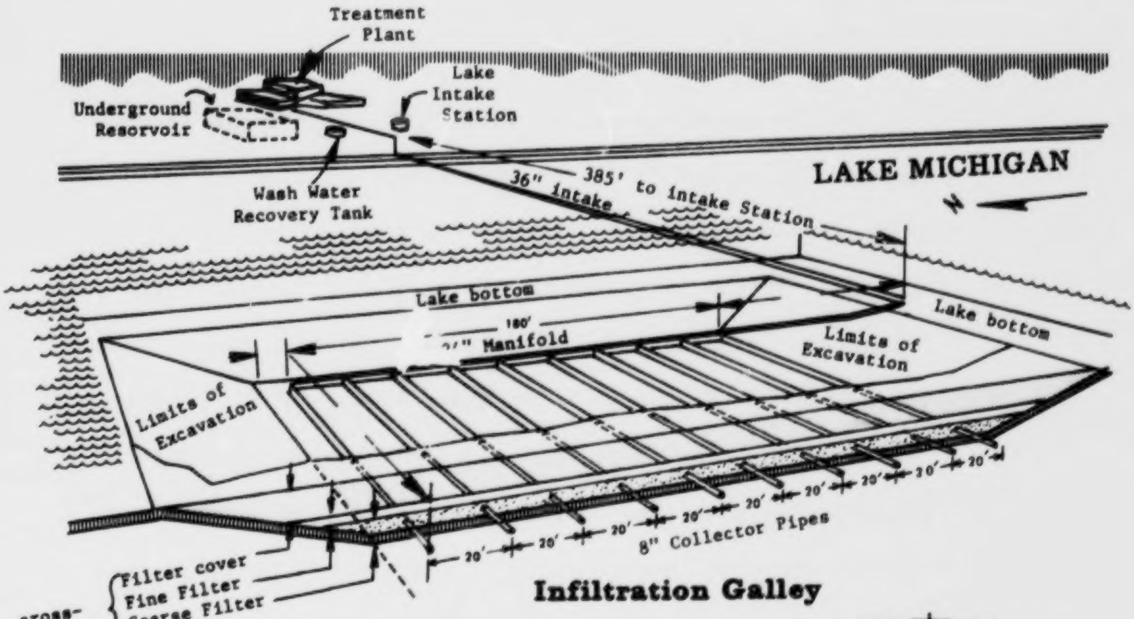

Delivery Point
Discharge Point
Filling Point
Touchpoint

Figure 8 SCREW PUMP

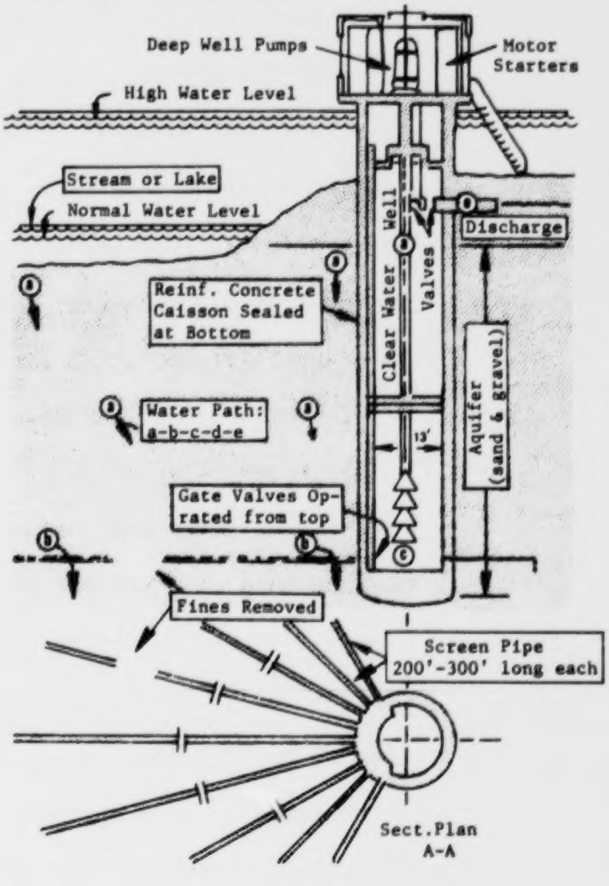
screens are projected horizontally into the aquifer through ports. The output of the collector well is limited and depends primarily on the permeability of the aquifer and number of screens. In the infiltration gallery, an artificial aquifer is placed over a screen pipe network, and water is drawn through the aquifer. (Figure 9) Fish entrapment is not a problem with these systems, and if biological studies determine that the organisms to be protected are small forms such as fish eggs, fish larvae, and invertebrates, it is conceivable that the infiltration or collector well system could be used as a method of water withdrawal. Use of infiltration systems however, may just transfer the point of entrapment to the lake bottom. If the infiltration area is large (many acres) in size, the velocity through the aquifer may be low enough to prevent this. Studies are presently underway at the University of Washington evaluating the feasibility of using infiltration galleries to provide cooling water for a nuclear power plant.

G. Intake Water Velocities

The effectiveness of any of the above intake screening methods in preventing entrainment or entrapment of fish depends almost entirely on intake velocities at the mouth of the structure. Current velocities at the intake should be related to the sustained speeds, burst speeds, and cruising speeds of the fish species to be protected. Some of the studies reviewed indicated that velocities of 0.5 feet per second or two or three times the body


Treatment Plant
Underground Reservoir
Lake Intake Station
Wash Water Recovery Tank
385' to Intake Station
36" Intake
LAKE MICHIGAN
N
Lake bottom
180'
Manifold
Lake bottom
Limits of Excavation
Limits of Excavation
20'
8" Collector Pipes
Filter cover
Fine Filter
Coarse Filter
cross-section

Infiltration Galley


Deep Well Pumps
Motor Starters
High Water Level
Stream or Lake
Normal Water Level
Discharge
Clear Water Well
Valves
Reinf. Concrete Caisson Sealed at Bottom
Aquifer (sand & gravel)
Water Path: a-b-c-d-e
13'
Gate Valves Oprated from top
a
b
c
d
e
Fines Removed
Screen Pipe 200'-300' long each
Sect.Plan A-A

Radial Collector

Figure 9 INFILTRATION SYSTEMS

length of the fish per second, whichever is greater, would be adequate to protect the designated species and life stages.(38),(13),(48),(24),(3)

Some studies were reviewed which indicated that a velocity cap over the mouth of a vertical submerged intake was found to reduce the rate at which fish were drawn into the intake.(50) This modification which provides for a high horizontal approach velocity was developed after fish had been observed to react to horizontal velocity changes but were found generally ignoring vertical velocities. (Figure 10) If a velocity cap is to be used, the flow rate limitations expressed above may be altered.

H. Conclusion.

Careful site selection for a cooling water intake facility is the first line of defense in minimizing loss or damage to a fish population. Once the site is selected, any one or a combination of the above mentioned structures may be required for fish protection at a specific site since the geography and fish habitat of Lake Michigan vary significantly from location to location. It is inappropriate to recommend a single cooling water intake design for Lake Michigan based on best technology currently available.

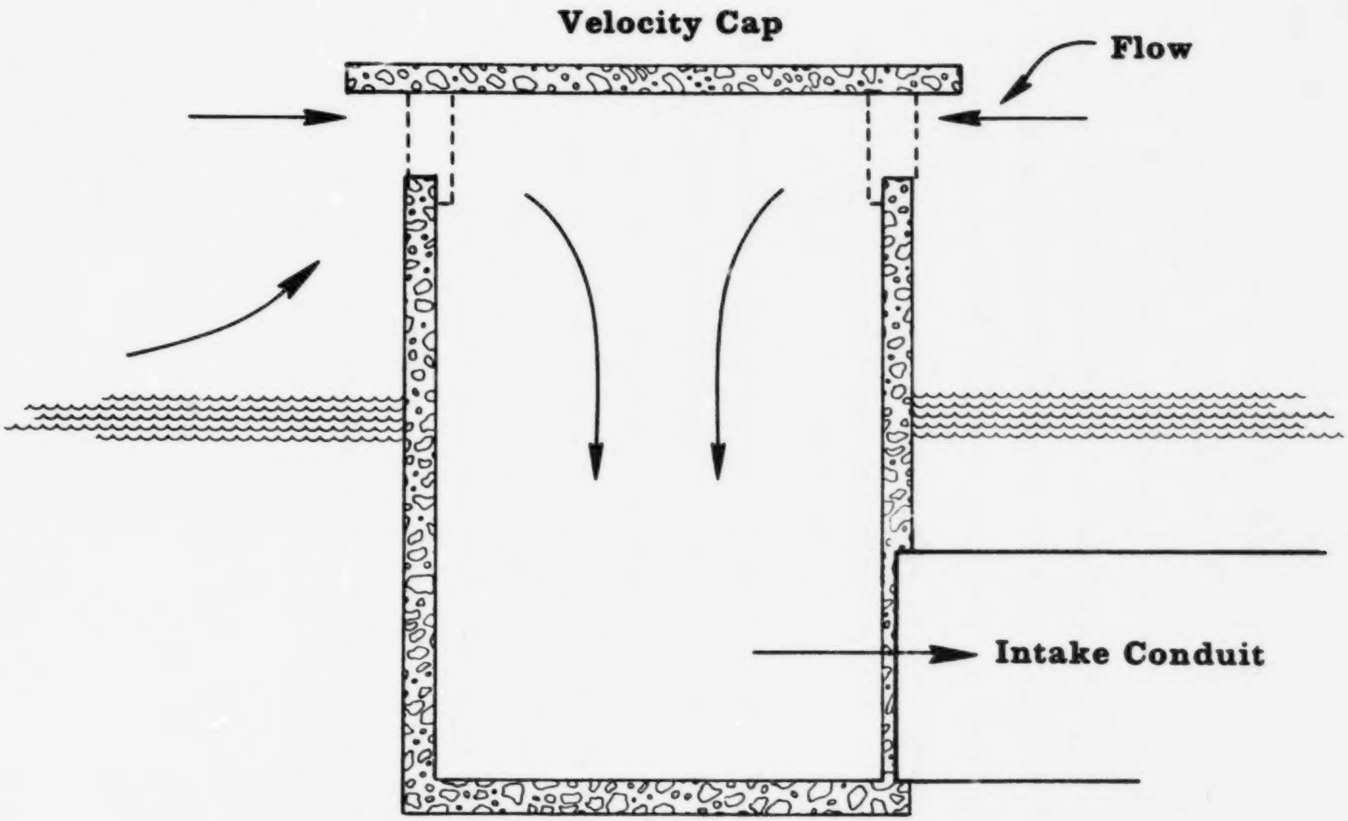

Velocity Cap
Flow
Intake Conduit

Figure 10 VELOCITY CAP ON OFFSHORE INTAKE STRUCTURE

IV. MONITORING PROGRAM

A. General

As indicated in Section II, there is a general concern regarding the loss of any aquatic life through intake entrainment and entrapment until the losses and their concomitant effects on the populations can be reasonably evaluated. Further, a review of Appendix C indicates that little quantitative information is available at this time on fish losses to make such an evaluation.

A monitoring program should be established for each water user, where use exceeds 100 cfs, for at least one year, to document numbers, weights, and length frequency distribution of each fish species entrapped. This information should be supplemented by estimates of numbers of fish eggs and larvae entrained in the intake water.

The monitoring program will meet two objectives: (1) provision of information to Federal and State regulatory agencies to determine compliance with applicable permits, regulations, etc., and (2) preparation of a general report directed to questions of best available technology, evaluation of losses as they relate to local and lake wide populations and future siting.

With respect to the general report, it is recommended that data from the monitoring programs be distributed by U.S. EPA to a study group such as the Lake Michigan Cooling Water Studies Panel (LMCWSP). This study group should in turn, with cooperation of the regulatory agencies, contract a consultant to prepare a report to meet the following purposes:

1. Estimate the total number, weight and length frequency distribution of fish species entrained and entrapped by various types of intakes in different areas of the lake.
2. Evaluate data collected to determine the effect of entrainment and entrapment on local and lake-wide populations of each fish species.
3. Evaluate parameters relating to intake design, location and water velocity that effect fish entrainment and entrapment. This information will be used to:
    (a) Further develop "best available technology" for cooling water intakes to reduce problems on Lake Michigan.
    (b) Develop best intake design and location criteria for future Lake Michigan plants.

The general report should meet the following schedule:

1. Submission of the results of monitoring program at each plant to the study group not later than February, 1975.
2. Completion of the report not later than September, 1975.

B. Monitoring Program for Existing Water Intakes

The primary objective is to determine the daily and seasonal variations in numbers, size and weight of all life history stages for fishes entrapped in intake systems.

1. Sampling Frequency. This must extend through a one-calendar year. Intensive sampling for eggs and larvae must be conducted one day per week for a 24-hour period as a minimum. As the

minimum effort for documenting entrapped adult and immature fish, sampling should be conducted for a period of 24 hours every fourth day. Properly conducted subsampling techniques are appropriate if numbers are excessive.

2. Sampling Methods. The distribution of fishes within the intake system and the water volume used must be quantified.

   a. Eggs and Larval Fish

      (1) Nets. When nets are the gear of choice, they must be accurately metered to determine flow, and should have a mesh size no greater than 351 μ. Nets should be set at several vertical depths at each sampling location to document variation due to possible vertical distribution of eggs and larvae within the intake system.

      (2) Submersible Pumps. When pumps are used, they should be of high capacity (100-200 GPM) to prevent avoidance of intake current by fish larvae. Possible effects of cavitation or mechanical pump effects should also be measured to estimate destruction of eggs and larvae. The pumped water must be filtered through a net with a mesh size no greater than 351 μ.

   b. Juvenile and Adult Fish

      Collections of all fish impinged on screening devices can be accomplished with fish collection baskets placed in the backwash sluiceway. Mesh size of the collection basket must be equal to or smaller than the intake screen mesh.

3. Sampling Data Required

   a. Plant operating data required during monitoring period includes:

      (1) Volume pumped, or number and rated capacity of circulating water pumps in operation during sampling interval.

      (2) Temperature - intake and discharge

      (3) Time started, duration and amount of warm water recirculation for intake tempering or deicing.

      (4) Total residual chlorine or other biocides contained in recirculating water during condenser cleaning.

      (5) Current velocity at intake(s) over range of water volumes used in plant operation.

      (6) Number of times screens are operated between sampling intervals if sampling is conducted every four days.

      (7) The distance from shore and depth from which the water is withdrawn.

   b. (1) Determine number and size of larval fish for each species collected.

      (2) Count and when possible identify eggs collected.

      (3) Determine volume of water sampled.

      (4) Quantify number of eggs and larvae as number per cubic meter in the intake water.

      (5) Count, measure (std. length), and weigh juvenile and adult fish collected from screening devices by species.

(6) Obtain a representative sample of each species to be eviscerated for determination of sex and breeding condition.

(7) Count the number of dead fish in the area which precedes the trash racks if the dead fish are too large to pass through the openings of the trash racks. Dead fish should be removed from area in front of trash racks prior to sampling.

(8) Note and quantify as above the number of Mysis relicta and Pontoporeia affinis collected in the intake water when sampling for fish eggs and larvae.

C. Monitoring Program for Proposed Water Intake Sites

The primary objective is to delineate near-shore areas where fish concentrate. These areas include spawning, nursery and feeding grounds, and migration routes. Documentation of phytoplankton, zooplankton, and benthic populations must be included.

1. Sampling Frequency. This must be adequate to demonstrate seasonal differences in presence of important fish species (See Sec. II). Sampling must extend through one calendar year as a minimum.

2. Sampling Methods. Methods which attempt to quantify both species and numbers must be used. Areas both in the water column and in the bottom must be sampled to allow for quantitative calculations of organisms per volume of water or unit of bottom area.

3. Intake Design. Model studies must be conducted to determine the proper design of intake structures, screening devices, and fish bypasses to minimize loss through entrapment.

4. Intake Design Evaluation. Evaluation of intake losses during plant operation must include an evaluation of the intake design resulting from 3 above. The same monitoring program as outlined for existing water intakes must be followed except that number and condition of fish bypassed must also be determined when bypass devices are used.

V. FURTHER STUDIES AND RESEARCH NEEDS

There are numerous areas where additional information is required to fully establish the best available technology for water intakes in Lake Michigan. In this regard, there is a need to know the following:

A. What constitutes a significant loss of fish to a given population, i.e., what numbers of what species at what life stage. Such information may require specific geographic reference to such lake zones as Green Bay, the northern island zone, the Grand Traverse Bay area, and the southern Michigan shore since distinct races of a species may exist in different parts of the lake.

B. Intake locations which are biologically unacceptable due to an inherent potential for significant losses of fish. This should be accomplished by a biological mapping of the lake, especially in those areas of the lake where intakes could realistically be proposed within the in-shore zone. Consideration should also be given to those areas of the lake where offshore power plants may be sited in the future. Such mapping should be done for each important species of fish present and for each life stage where it occupies another water mass, the period of occurrence of each life stage should be described, and, where appropriate, should be accompanied by associated temperatures, depths, and substrate description. Historical, as well as present distributions, should be documented. It is believed that fish distributions which existed before the advent of the sea lamprey and over-fishing, will regain some degree of their previous importance to the fishery following restabilization from the present state of flux. Mapping would identify areas of fish concentration such as migratory routes, depths of concentrations, spawning and nursery grounds, and overwintering areas. The order of mapping and extent of the effort devoted to detail should follow the order of importance of the species.

C. The optimum working characteristics of the various devices used in reducing losses of entrapped fish, the parameters and design variables subject to manipulation to reduce loss are listed below:

1. Approach velocity of the water entering and bypassing the intake to the condenser system.
2. The angle of the protectiong device to the direction of flow of the intake water.
3. Type of screening device (perforated plate or woven wire screen) and opening size of the screen employed.
4. Rate of travel of traveling screens.
5. Dimensions of the bypass.
6. Flow characteristics.
7. Lighting characteristics.
8. Length of guidance system without a bypass.

Biological variables influencing the above are the species of fish of concern, the size of the fish, the swimming speed of the fish, and the water temperature as it influences the swimming speed of the fish. It follows that these parameters must be investigated for each species of interest. (Item A, if determined early, may indicate that certain species and/or life stages do not warrant such intensive study.)

D. The feasibility of reducing losses of small fish by screening or passing them through the condenser system unharmed. The above is predicated upon knowing the thermal, physical, chemical, and mechanical tolerances of the fish.

E. To find an effective means of deicing intakes without the disadvantage of recycling heated discharge water. The "bubble screen" has been suggested both as a deterrent to fish and as a method of circulating bottom waters for deicing. Alternative construction materials and techniques which are less conducive to ice accumulation should also be investigated.

F. Alternate devices for most effective fish conservation at each specific site. Development of more effective and more economical devices should be fostered. To accomplish this, State and Federal environmental protection agencies could participate in cost sharing with the industry for research and development to reduce significant losses of aquatic life. Some items for investigation would include: velocity cap studies, cavitation prevention studies, development of anti-fouling agents which reduce hazards to aquatic life, screen design testing, horizontal traveling screen development, and others as the needs arise and innovations evolve.

VI. BIBLIOGRAPHY*

(1) Anon. 1957. Fish Protection at the Tracy Pumping Plant Central Valley Project California. U.S. Dept. of Interior, Bureau of Recreation, Region II, and Fish & Wildlife Service, Region I.

(2) Alevras, R.A. 1973. Status of Air Bubble Fish Protection Systems at Indian Point Stations on the Hudson River. Paper presented at Entrainment and Intake Screening Workshop. Johns Hopkins University (Proceedings to be published), Baltimore, Maryland.

(3) Bainbridge, R. 1958. The Speed of Swimming of Fish as Related to Size and to Frequency and Amplitude of the Tail Beat. Exp. Biol. 35: 109-133.

(4) Bates, D.W. and R. Vinsonhaler. 1956. Use of Louvers for Guiding Fish. Trans. Amer. Fish. Soc. 86: 38-57.

(5) Bates, D.W., E.W.Murphey. 1970. Design and Operation of a Cantilevered Traveling Fish Screen (Model V). U.S. Fish and Wildlife Service. Spec.Sci.Rpt. Fisheries No. 608: 6-15.

(6) Beamish, F.W.H. 1970. Oxygen Consumption of Largemouth Bass _Micropterus salmoides_ in Relation to Swimming Speed and Temperature. _J. Fish. Res._ Bd. Canada 48(6): 1221-1223.

(7) Bell, M. 1973. Personal communication. University of Washington, School of Fisheries, Seattle, Washington.

(8) Bibko, P., and L. Wortanen. 1973. Effects of Light and Bubbles on the Swimming Behavior of the Striped Bass _Morone Soxatilis_. Paper presented at Entrainment and Intake _Screening Workshop_. Johns Hopkins University (Proceedings to be published), Baltimore, Maryland.

(9) Bohan, J.P. and J.L. Grace. 1970. Mechanics of Stratified Flow Through Orifices. ASCE, Nat. Water Res. Eng. Meeting.

(10) Brett, J.R. and D.F. Alderdice. 1958. Research on Guiding Young Salmon at Two British Columbia Field Stations. J. Fish. Res. Bd. Canada 117: 1-75.

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*Includes literature cited and reviewed.

BIBLIOGRAPHY, Cont'd.

(11) Burrows, R.E. 1954. Electrical Diversion Weir Proves Practicable at Entiat. Pro. Fish. Cult. 16(4): 152.

(12) Combs, B.D. 1973. Personal communication. Abernathy Salmon Cul. Dis. Cents., Longview, Washington. Conversation relative to work reported in Branch of Fishery Biol. Ann. Rpt. 1956, p. 15.

(13) Coots, M. 1956. Some notes on biological investigations of the perforated plate fish screen. State of California, Dept. of Fish and Game. Inland Fisheries Administration Report No. 56-8: 1-11.

(14) Coutant, C.C. 1969. Temperature, Predation and Behavior. Chesapeake Science 10(3-4): 261-274.

(15) Coutant, C.C. Part of Nat. Acad. Sci. Temperature Section of Committee Report on Water Quality Criteria. (In preparation)

(16) Cramer, F.K. and R.C. Oligher. 1964. Passing Fish Through Hydraulic Turbines. Trans. Amer. Fish. Soc. 93(3): 243-259.

(17) Danson, J.O. 1967. Alewive Problems at Waukegan Generating Station. J. American Water Works Asso. 59(1): 114-119.

(18) Ducharme, L.J.A. 1972. An Application of Louver Deflectors for Guiding Atlantic Salmon. (Salmo salor) Smolts From Power Turbines. J. Fish. Res. Bd. Canada. 29(10): 1397-1404.

(19) Eicher, G.J. 1964. Round Butte Dam fish Handling Costs 2.5% of Total Project Outlay. Electrical World, February.

(20) Eicher, G.J. 1960. Fish Bypass Experience at PGE's New Hydro Projects. Electric Light & Power, March !, pp. 62-65.

(21) Eicher, G.J. 1973. Personal communication. Entrainment and Intake Screening Workshop. Johns Hopkins University, Baltimore, Maryland.

(22) Goodyear, C.P. 1972. A Simple Technique for Detecting Effects of Toxicants or Other Stresses on a Predator Prey Interaction. Trans.Amer.Fish.Soc. 101(2): 367-370.

(23) Holmes, H.B. 1948. History, Development and Problems of Electric Fish Screen. Spec.Sci.Rpt.Fisheries No. 53: 1-63.

BIBLIOGRAPHY, Cont'd.

(24) Houde, E.C. 1969. Sustained Swimming Ability of Larvae of Walleye (Stizostedion vitreum vitreum) and Yellow Perch (Perca flavescens). J.Fish.Res.Bd. Canada 26(b): 1647-1659.

(25) Hunter, J.R. 1964. Net avoidance Behavior of Carp and other Species of Fish. J.Fish.Res.Bd.Canada 21(3): 613-633.

(26) Jensen, L. 1973. Personal communications. Johns Hopkins University, Baltimore, Maryland.

(27) Kerr, J.E. 1953. Studies on Fish Preservation at the Contra Costa Stream Plant of the Pacific Gas and Electric Company. State of California Dept. of Fish & Game. Fish Bull. 92: 1-66.

(28) Kobayaski, K., S. Igarashi, Y. Aiiko, K. Hoyashi. 1959. Studies on Air Screen in Water. Bulletin Faculty, Fish. Hokkaidu University 19(3): 222-228.

(29) Kupka, K.H. 1964. A False Weir Fishtrap. The Canadian Fish. Cul. 22: 53-57.

(30) Lagler, K.F., J.E. Bardach, and R.R. Miller. 1962. Icthyology. John Wiley & Sons, Inc., New York, 545 pp.

(31) Laurence, G.C. 1972. Comparative Swimming Abilities of Fed and Starved Larval Largemouth Bass Micropterus salmoides. J.Fish.Biol. 4(1): 73-78.

(32) Long, C.W. 1968. Diel Movement and Vertical Distribution of Juvenile Anadromous Fish in Turbine Intakes. U.S. Fish and Wildlife Service. Fish Bull. 66(3): 599-609.

(33) Merriman, D. 1970. The Calefaction of a River. Scientific American 222(5): 42-52.

(34) Moore, R.E. 1972. Report Survey of Large Volume Water Intake System Velocities and Fish Swimming Speeds in the Great Lakes. Submitted to the Cleveland Electric Illumination Company, Illuminating Building, Cleveland, Ohio.

(35) Moore, H.L. and H.W. Newman. 1956. Effects of Sound Waves on Young Salmon. U.S. Fish & Wildlife Service. Spec. Sci. Rpt. Fisheries No. 172.

(36) Muir, J.F. 1959. Passage of Young Fish Through Turbines. J. Power Div. Pro. Amer. Soc. Eng.: 23-49

BIBLIOGRAPHY, Cont'd.

(37) Nambiar, K.P.P., Y. Hiyama, T. Kusaka. 1970. Behavior of Fish in Relation to Moving Nets. III. Effect of Water Temperature and Diurnal Rhythm and the Avoidance Responses of the Fish Bull. Jap. Soc. Fish. 36: 476-480.

(38) Pugh, J.R., G.E. Monan, and J.R. Smith. 1971. Effect of Water Velocity on the Fish-Guiding Efficiency of an Electrical Guiding System. U.S. Fish and Wildlife Service. Fish Bull. 68(2): 307-324.

(39) Prentice, E.F. 1973. Nat. Marine Fisheries Service, U.S., Dept. of Commerce, 104 Fern Ct., Portland Orchard, Washington.

(40) Riesbol, R.S., and P.J.L. Gear. 1972. Application of Mechanical Systems to Alleviation of Intake Entrapment Problems. Presented at the Atomic Industrial Forum Conference on Water Quality Considerations, Washington, D.C. October 2, 1972, 22 pp. plus figures.

(41) Robinson, J.B. 1971. Effects of Passing Juvenile King Salmon Through a Pump. Prog. Fish. Cul. 33(4): 219-233.

(42) Ruggles, C.P. and P. Ryan. 1964. An Investigation of Louvers as a Method of Guiding Juvenile Pacific Salmon. Canadian Fish. Cul. 33: 1-68.

(43) Samio, E. 1960. Studies on Bubble Net. I. Driving and Intercepting Effects on Some Freshwater Fish. Memoirs Fac. Fish. Kagoshima University 8: 140-144.

(44) Sharp, F.P. 1961. A Midsummer Plant of Rainbow Trout in a Stratified Tennessee Impoundment. Prog. Fish. Cul. 23(4): 152-155.

(45) Shishkova, E.V. 1958. On Fish Reaction to Sound and to Noise Spectra of a Trawler. (O Reakts!! Ryby na zvak I Shumouykher traulera) M., Rybroe Khoziaistvo, No. 3: 33-39, March.

(46) Tarzwell, C.M. 1972. An Argument for the Open Ocean Siting of Coastal Thermal Electric Plant. J. Environ. Qual. 1(1): 89-91.

(47) Trembley, F.J. 1962. Effects of Cooling Water from Steam-Electric Power Plants on Stream Biota. U.S. Dept. of Health, Education and Welfare, Public Health Service. Biol. Prob. in Water Pollution 3rd Seminary: 334-345.

BIBLIOGRAPHY, Cont'd.

(48) U.S. Atomic Energy Commission (Directorate of Licensing). 1972. Final Environmental Statement on Operation of Indian Point Nuclear Generating Plant, Unit No. 2. Consolidated Edison Company of New York, Inc., Docket No. 50-247.

(49) Warner, G.H. 1956. Report on the Air-Jet Fish-Deflector Tests. Prog. Fish. Cul. 18(1): 39-41.

(50) Weight, R.H. 1958. Ocean Cooling Water System for 800 MW Steam Power Station. Proc. ASCE. 84(PO6):1888-12, 1888-16.

(51) Yutaka, I. and M. Oqura. 1959. Study on the Fish Gathering Effects of Air Curtains. J. Tokyo University of Fish. 45(2): 173-177.

(52) Zolotov, G.N. 1963. Observations on Reactions of Young Fish to a Moving Electric Field. Ikhtiol Rybn Khoz Akad Nauk Kazakhsk SSR. 4:175-186. Biol. A6. 46(3) Abst. No. 9778(1965).

VII. APPENDICES

A. U.S. EPA Statement at Public Session LMEC on November 9, 1972.

B. List of Committee members, participants, and report reviewers.

C. Biota of the Nearshore Waters of Lake Michigan and Mortality of Organisms Caused by Water Intake Structures.

D. Water Intake Information for Lake Michigan.

APPENDIX A

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
STATEMENT CONCERNING
LAKE MICHIGAN THERMAL PROBLEM*

PUBLIC SESSION OF THE
LAKE MICHIGAN STATES AND THE
ENVIRONMENTAL PROTECTION AGENCY
November 9, 1972

The questions raised by the construction of several large power plants on the shores of Lake Michigan have been a matter of urgent concern to and have occupied countless hours of the Lake Michigan Enforcement Conference. In briefest summary I shall attempt to outline the facts underlying the problem. Six nuclear electric generating stations are in various stages of construction in the four Lake Michigan states; several of the plants are scheduled to be in full operation at various dates in 1973.

At the third session of the Lake Michigan Enforcement Conference (March 23-25, 1971) EPA Administrator Ruckelshaus proposed to the state conferees for their adoption a water quality standard whose implementation would require the installation of auxiliary cooling facilities at the nuclear power plants under construction. The essence of Administrator

*Note pages 6, 8 and 9

Ruckelshaus' recommendation was that waste heat discharges located on Lake Michigan in excess of 1/2 billion BTU/hr which had not begun operation as of March 1, 1971 shall have closed cycle cooling facilities associated with their operation.

Under the Federal Water Pollution Control Act as amended through 1970, water quality standards consisted of three elements: criteria, uses, and an implementation plan geared to attain the criteria and uses. The new FWPCA states that best practicable control technology shall be achieved not later than July 1, 1977. However, if the application of best practicable control technology does not attain water quality standards then more stringent limitations will be required. It should be noted that the water quality standards which will be considered by the Environmental Protection Agency for approval or disapproval, will consist only of criteria and use designations. Implementation plans are no longer subject to approval by EPA as part of water quality standards. In place of implementation plans incorporated in the standards, the new Act imposes a continuing planning process requirement on each state which requires the state to have comprehensive control plans including implementation plans for all navigable waters within the state.

At the March 23-25, 1971 session of the Lake Michigan Enforcement Conference, the conferees made certain findings and recommendations. Most of these findings and recommendations were approved by Administrator Ruckelshaus on May 14, 1971 and forwarded to the states for implementation.

Subsequent to the issuance of the approved findings and recommendations, the four Lake Michigan states took certain actions relating to implementing the conference recommendations. Basically these actions were consummated in the adoption by the states of thermal water quality standards. The principal elements of the adopted conference recommendations and those elements considered by the states for adoption as water quality standards were as follows: maximum temperature limits, specific definition of mixing zones, implementation schedules, and guides on restrictions on intake mechanisms, discharge plumes, and monitoring. The conference specifically adopted a recommendation which required closed cycle cooling systems on all new thermal waste dischargers above a certain size.

Recognizing the risk of summarizing what each state adopted, I have attempted to do that. The summary is as follows:

INDIANA: Essentially adopted all of the conference recommendations.

ILLINOIS: Essentially adopted all of the conference recommendations with the exception of the closed cycle cooling requirements on all plants not under construction as of March 1, 1971 and the plan of implementation on bringing older sources into compliance with the general conference recommendations.

MICHIGAN: Essentially adopted all of the conference recommendations with the exception of the closed cycle cooling requirements on new sources and the plan of implementation on bringing older sources into compliance with the general conference recommendations. The state did not adopt the mixing zone definition, leaving that determination to a case-by-case basis.

WISCONSIN: Adopted the monthly maximum criteria exempting certain areas from the requirements. Other requirements, including mixing zone and installation of closed cycle cooling, were not adopted.

Under the new Act the standards submitted to EPA by the four states must be approved or rejected by January 18, 1973. If EPA fails to take action by January 18, 1973, the standards submitted by the states will automatically be approved. It is EPA's intention to review and act on all of the Lake Michigan thermal standards by the required date. At this time it would appear that much of what is in the submitted standards is approvable.

This disposition of the pending thermal water quality standards will not, however, resolve the Lake Michigan thermal problem which faced the Lake Michigan Enforcement Conference in each of its sessions. We know that the thermal question is not readily resolvable not only from our own experience but from a reading of the new Federal Water Pollution Control Amendments of 1972.

Congress considered voluminous testimony in their deliberations on the new bill. On the basis of the evidence they concluded that best practicable control technology would be required for all municipalities and industries by July 1, 1977 and best available technology by July 1, 1983. Congress obviously felt on the basis of the testimony they heard that all of the answers were not in on the question of thermal pollution. While they recognized it as a pollutant and a problem, they saw fit to address the question in a special way in various sections of the Act.

Specifically, Congress provided for the establishment of a program to start to get some asnwers on the thermal problem. The new Act requires the Administrator, in cooperation with State, Federal, and public and private organizations, to conduct comprehensive studies on the effects and methods of controlling thermal discharges. In evaluating alternative methods of control, the studies are required to consider the state of the art, economic feasibility, including cost-effectiveness, and the total impact on the environment. The studies will consider methods of minimizing adverse effects and maximizing beneficial effects of thermal discharges. The results of the studies are to be reported not later than 270 days after October 18, 1972 and will be generally available. The results of the studies will be considered in the permit issuing process set up by the Act in developing thermal water quality standards. [See Sec. 104(t)].

Basically, to control all municipal and industrial discharges, the Act establishes a national permit system superseding the program set up under the Refuse Act. EPA is to determine what best practicable control technology is for various industries, and is to set effluent limitations within one year. EPA is to administer the permit program until such time as a state satisfies the Administrator that it has the statutory capability to manage the program, at which time the program will be transferred by EPA to the state. [See Sec. 402].

With regard to thermal pollution a special section provides that thermal discharges will be subject to the requirements of best practicable control technology (existing sources and those under construction) and best available control technology (new sources). [See Sec. 301 and 306]. If the thermal discharger can prove at a public hearing to the satisfaction of the Administrator (or a state if the permit authority has been transferred to the state) that the prescribed effluent limitation is not necessary to assure the protection and propagation of a balanced indigenous population of shellfish, fish and wildlife, then the Administrator may impose a less stringent effluent limitation. [See Sec. 316].

A problem of great concern during past Enforcement Conference discussions has been the entrainment and destruction of aquatic biota during cooling water usage. The new statute provides that cooling water intake structures, unlike heated effluents, must immediately reflect the best technology available for minimizing adverse environmental impact. [See Sec. 316(b)].

On the basis of the new Act, the control of thermal discharges will be handled by the permit process. There are presently 27 Lake Michigan power plants in the pre-operational and operational stage. Additionally, there are numerous other lesser thermal discharges to the lake. The Act provides for the issuance of permits in the interim before final effluent limitations are promulgated by EPA, subject to such conditions as the Administrator determines to be necessary to carry out the provisions of the Act. However desirable it may be to make an early interim decision on what the statutory requirement of best practicable control technology is, we must fully appreciate the consequences. As regards significant thermal discharges, determination of best practicable control technology should be one meant to last for a number of years since the undertaking of most thermal control programs are usually long term projects. Construction of facilities and the engineering attendant to such construction is usually extended over years rather than months.

Until the promulgation of effluent limitations required by the statute has been effected, Lake Michigan power plant permit applications will be processed in the following manner:

1. Each permit application will initially be processed on the basis of compliance with Federally approved water quality standards. Under the statute if it is determined that best practicable control technology for thermal discharges requires

more than the achievement of water quality standards such as off stream cooling, the discharger will be required to install such facilities unless the discharger can demonstrate that a less stringent effluent limitation will assure the protection and propagation of a balanced indigenous population of shellfish, fish and wildlife.

2. During the term of the permit a comprehensive monitoring program will be undertaken to evaluate the effects of the thermal discharges upon the environment.
3. The permit will be issued for a relatively short period (not to exceed three years). However, the permit shall be terminated whenever either of the following occurs: (1) a finding that the effluent being discharged does not assure the protection and propagation of a balanced indigenous population of shellfish, fish and wildlife, or (2) the promulgation of final effluent limitations defining best practicable control technology for thermal discharges.

We must proceed to see that other questions related to cooling water usage are addressed promptly. First on this list is the requirement to have cooling water intake facilities reflecting best technology available. To develop the necessary data base on this question, EPA is suggesting the formation of a technical committee to undertake the evaluation of existing data and to make appropriate recommendations to EPA and the Lake Michigan states. It is our suggestion that the committee should consist of two representatives named by each of the states and two persons named by EPA. It is my suggestion that Dr. Robert W. Zeller, Director, Region V EPA Surveillance and Analysis Division, chair this committee.

On another and more general problem, the EPA and the States have in the past discussed the need for adequate monitoring of programs to assess damage to the aquatic environment attributable to existing and planned cooling water uses. As required under the licensing procedures of the Atomic Energy Commission and under certain state requirements, a number of studies have been conducted to assess damage. As was discussed at the September session, it appears that criteria do not exist to trigger the installation of appropriate corrective measures should damage become evident. A mechanism is also lacking to make an overall assessment of the damage that may occur to the lake's eco-system from waste discharges scattered at various points around the lake. This lack exists because present studies are geared toward a local, or at best regional assessment of a problem and not to the impact on the overall lake. Both monitoring elements, i.e., local and lakewide are important to assess damage to the lake. To address this problem, I suggest the formation of a technical panel to be composed of at least three representatives from each Lake Michigan state and three representatives from the EPA. The state representatives may be other than state employees and should be members of the academic community, persons employed by utilities, and members of environmental and other citizens groups. It would be my suggestion to have Dr. Andrew McErlean, Senior Staff Biologist in the Office of Enforcement and General Counsel in Washington, to chair this technical panel. Dr. McErlean is eminently qualified to head this most important group. The charge of this panel would be

> to review background information dealing with past, present and future studies relating to thermal discharges to Lake Michigan;
>
> to make assessments as to whether the individual studies concerning thermal discharges will adequately assess damage attributable to that cooling water use;
>
> to assess the pertinence of individual localized studies to monitor changes in the overall lake eco-system;
>
> and to recommend, as necessary, additional efforts that should be expended to assess environmental effects of the use of Lake Michigan water for cooling.

I am prepared to lend such assistance as I can to fashion the kind of a program which will collect and evaluate the facts and to assure maximum protection to the public resource, as well as fair play for the industry.

APPENDIX B

Committee Members

Robert W. Zeller, Chairman	U.S. EPA, Region V	Chicago, Ill.
Charles H. Walburg	BSF&W, USDI	Yankton, S.D.
D. V. Stevens	Northern Indiana Public Service Co. (NIPSCO)	Hammond, Ind.
Samuel Moore	Indiana Stream Pollution Control Board	Indianapolis, Ind.
Peter Howe	Commonwealth Edison	Chicago, Illinois
William V. Pye	Illinois EPA	Springfield, Ill.
Jerry McKersie	Wisconsin DNR	Madison, Wis.
Tom Wirth	Wisconsin DNR	Madison, Wis.
John Scott	Michigan DNR	Lansing, Mich.
James Truchan	Michigan DNR	Lansing, Mich.

Committee Participants

Carl T. Blomgren	Ill. EPA	Chicago, Ill.
C. W. Kern	NIPSCO	Hammond, Ind.
Charles R. Nichols	U.S. EPA, Hdqrs.	Wash. D.C.
J. Howard McCormick	U.S. EPA, NWQL	Duluth, Minn.
David Stoltenberg	U.S. EPA, Region V	Evansville, Ind.
Max Anderson	U.S. EPA, Region V	Evansville, Ind.
Donald Wallgren	U.S. EPA, Region V	Chicago, Ill.
Don Meyers	U.S. EPA, Region V	Chicago, Ill.

Acknowledgments

Dr. Charles Coutant	Oak Ridge Nat'l Lab.	Oak Ridge, Tenn.
Dr. John C. Geyer	Johns Hopkins Univ.	Baltimore, Md.
Dr. Loren C. Jensen	Johns Hopkins Univ.	Baltimore, Md.
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Mr. Eicher	Portland General Electric	Portland, Oregon
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APPENDIX C

BIOTA OF THE NEARSHORE WATERS OF LAKE MICHIGAN AND MORTALITY OF ORGANISMS CAUSED BY WATER INTAKE STRUCTURES

by:
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North Central Reservoir Investigations
Yankton, South Dakota 57078

BIOTA OF THE NEARSHORE WATERS OF LAKE MICHIGAN AND MORTALITY OF ORGANISMS CAUSED BY WATER INTAKE STRUCTURES

By
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Existing water intake structures on Lake Michigan are located near shore at depths within the 30-foot contour. The volume of water between the 30-foot contour and the shore has been termed the beach water zone (U.S. Department of the Interior, 1970). For convenience, we have retained this connotation, and in this report have used near shore and inshore to also denote waters within the 30-foot contour. This zone is important from the standpoint of man. Not only is it the most used by man as a source of water for domestic, industrial, and cooling purposes and as an area for fishing, boating, and swimming, but it is also important biologically. Many species of Lake Michigan fish occupy these waters at one time or another during their life cycles. Some species spend much of their lives near shore while others are present only when immature or during migrations. Besides fish, these waters contain populations of zooplankton, phytoplankton, and bottom fauna.

The area of the lake within the 30-foot contour (beach water zone) has an average width of about 1 mile although the average is 2 miles at the south end of the lake. Its surface area is 1,533 square miles, or about 7 percent of the lake surface, including Green Bay.

The volume is 4.4 cubic miles, or about 0.4 percent of that of the entire lake (U.S. Department of the Interior, 1970). While the waters of this zone may not be distinct from the rest of the lake, biota that frequent this area will be subjected to municipal, industrial, and utility water intakes and discharges.

Biota Found Within the Beach Water Zone

A. Fishes

In this report, our discussion concerns those species which are known to have been entrained or impinged on screens in waters withdrawn from Lake Michigan. In general, these fishes are those which are presently most common in inshore waters during some stage of their life. The alewife is the most abundant followed by other species such as yellow perch, slimy sculpin, smelt, spottail shiner, trout-perch, lake trout, coho salmon, steelhead, and bloater. Fishes collected from traveling screens are listed in Table I. Other fishes are known to occur in inshore waters but have not yet been identified from collections taken on traveling screens. Species important to sport or commercial interests are northern pike (*Esox lucius*), walleye (*Stizostedion vitreum*), smallmouth bass (*Micropterus dolomieui*), brook trout (*Salvelinus fontinalis*), lake herring (*Coregonus artedi*), and lake whitefish (*Coregonus* sp.)

Table 1 --
List of fishes collected from travelling screens, Lake Michigan

Common name	Scientific name
Bowfin	*Amia calva*
Gizzard shad	*Dorosoma cepedianum*
Alewife	*Alosa pseudoharengus*
Chinook salmon	*Oncorhynchus tshawytscha*
Coho salmon	*Oncorhynchus kisutch*
Brown trout	*Salmo trutta*
Rainbow trout (steelhead)	*Salmo gairdneri*
Lake trout	*Salvelinus namaycush*
Bloater	*Coregonus hoyi*
Smelt	*Osmerus mordax*
White sucker	*Catostomus commersoni*
Longnose sucker	*Catostomus catostomus*
Carp	*Cyprinus carpio*
Longnose dace	*Rhinichthys cataractae*
Spottail shiner	*Notropis hudsonius*
Emerald shiner	*Notropis atherinoides*
Channel catfish	*Ictalurus punctatus*
Black bullhead	*Ictalurus melas*
Burbot	*Lota lota*
Trout-perch	*Percopsis omiscomaycus*
Yellow perch	*Perca flavescens*
Johnny darter	*Etheostoma nigrum*

Table I, Cont'd.
List of fishes collected from travelling screens, Lake Michigan

Common name	Scientific name
Rock bass	Ambloplites rupestris
Bluegill	Lepomis macrochirus
Slimy sculpin	Cottus cognatus
Nine-spine stickleback	Pungitius pungitius

The distribution of fishes common to the nearshore waters by season and age is described below. It should be noted that abundance of the various species differs between different areas of the lake.

Alewife

The alewife provides the largest commercial catch of any species in Lake Michigan. In recent years, its numbers appear to have more or less stabilized at a level considerably below that of the middle 1960's. It is also important as a major food for salmon and trout. The alewife is also known for its mass mortalities and consequent littering of beaches.

This species is found over the entire lake but is probably most abundant in the southern portion and (except in winter) in Green Bay. Although the depth distribution changes with the season, taking the year as a whole, they occupy all depths. During the winter, they are found in the deepest parts of the lake. In the spring, from mid-April through June, they move into the shallow waters along shore and into rivers to spawn. Most spawning occurs in June and July in rivers but is also common in sheltered areas of Green Bay and occasionally along the protected shoreline of Lake Michigan proper. Alewives are pelagic spawners and eggs settle to the bottom and adhere to the substrate; eggs hatch in about four days. Although some movement of adults to deeper areas begins soon after the spawning season, large numbers remain in shallow waters throughout the summer; mass movement to deeper water occurs in the fall.

Soon after hatching, which is primarily from mid-June to mid-August, young are carried into the lake and most are found in the upper 10 to 20 feet of water very near shore. As they grow older, some rapidly disperse into the upper warm levels over deeper areas and may be found in midlake by late summer (Wells, 1968). By October, many young (Most less than 3 inches) are again found on the bottom in shallow water. Total length of fish by the end of their first year of life ranges from 2.0-4.5 inches.

Yellow perch

The yellow perch is important to the sport fishery in Lake Michigan and was once a valuable commercial species[1/]. It declined drastically lakewide in the late 1950's to the middle 1960's, but has partially recovered in some areas. The species is now most abundant along the eastern and southern shores of Lake Michigan proper from Ludington, Michigan to the Illinois-Indiana boundary and in Green Bay and Grand Traverse Bay. It is relatively uncommon but apparently increasing somewhat along the western shore of Lake Michigan

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[1/] Because of scarcity, State of Michigan closed commercial season in 1970 proper. Fair numbers are reported around harbors and jetties at Kenosha, Racine and Milwaukee, Wisconsin. Few are found in northern Lake Michigan except in the aforementioned bays.

During the first 2 years of life, they are most abundant from the shore to a depth of 30 feet. Older fish are generally found from the shore to a depth of 100 feet (especially shore to 60 feet); they are found in shallower water during the warm months than during the cold months.

Yellow perch spawning areas are not completely known but most are located along the southern and eastern shores and in Green Bay among weed beds or on rocky shoals. These areas provide substrates to which the ribbon-like egg masses can cling. The spawning season varies somewhat from year to year, but usually occurs between May 15 and July 1. Larvae are pelagic, mostly in inshore areas, and may be found from the surface to at least a depth of 20 feet in June and July. Total length of yellow perch by the end of the first year of life ranges from 3.5 to 4.5 inches.

Slimy sculpin

The slimy sculpin is an important food for lake trout and adult yellow perch. It is abundant and of wide distribution in Lake Michigan. Most are at depths greater than 30 feet, but some of all ages are found in water less than 30 feet deep, especially in winter and spring. They spawn in deep water in the spring; young are usually found at depths exceeding 100 feet.

Smelt

The smelt is important to both the commercial and sport fishermen in Lake Michigan. It is also important in the diet of lake trout. This species is found throughout the lake, but is most common in the western and northern portions, particularly Green Bay. Adults move into tributary streams and shallow lake shore areas to spawn in late April and early May. After spawning, most adults return to waters deeper than 30 feet

Once hatched, the fry rise close to the stream surface and drift downstream and enter the nearshore waters of the lake. Smelt fry have been found near shore at depths from 5 to 20 feet. How long the fry remain in shallow water is not known, but Wells (1968) demonstrated that most remain in the warm upper strata until late summer. In Lake Erie, Ferguson (1965) found that young smelt frequent shallow epilimnial waters and at times are heavily concentrated near shore. The total length of smelt at the end of their first year of life ranges from 2 to 4 inches.

Spottail shiner

The spottail shiner is a forage species sometimes found in the diet of lake trout and yellow perch. It lives near shore at all times of the year and is most common in the southeastern part of the lake from Grand Haven, Michigan to Michigan City, Indiana and in Green Bay. Total length of fish at the end of their first year of life ranges from 2 to 3 inches. Length at the end of the second year ranges from 3.5 to 4.5 inches.

Trout-perch

This species is sometimes found in the diet of lake trout and yellow perch. It is present throughout the lake but is most abundant in the southeast and in Green Bay. In late spring and summer months many are found near shore. They frequent waters deeper than 30 feet at other times of the year. Spawning occurs in shallow waters in June, July and August along beaches and perhaps in streams. Young-of-the-year frequent inshore areas. Total length at the end of the first year of life averages about 2 inches and at the end of the second year 3 to 4 inches.

Lake trout

The lake trout is historically one of the most important fish species in Lake Michigan from both a commercial and sport fishing standpoint. The population was reduced because of overfishing in the 1930's and 1940's, and finally all but eliminated by the parasite sea lamprey (*Petromyzon marinus*) during the 1950's. Attempts in the past two decades to control the lamprey and reestablish the lake trout appear successful. Large numbers of yearlings are annually planted in Lake Michigan from State and Federal hatcheries. These fish range from 5 to 6 inches in total length and all are fin-clipped.

This fish is found throughout Lake Michigan and it is once again important in the sport fishery. During the winter, it can be found scattered at all depths, but during the warmer months most are found at depths from 40 to 150 feet. At this time they seldom occupy waters where temperatures exceed 65° F; preferred temperature is about 50° F.

During spring months, many lake trout inhabit the beach water zone. This species spawns in the fall at depths as shallow as 3 feet; maximum depth of spawning is not known, but historically some native fish were known to spawn at depths exceeding 200 feet. Typical spawning grounds are rocky (gravel, rubble, boulders) wave or current swept shoals. Natural reproduction apparently has been unsuccessful in recent years since no naturally spawned fish have been collected.

Coho salmon

This fish was first introduced in 1966 and it is now one of the most sought after sport fish in Lake Michigan. Large numbers of hatchery-reared fish are released into the lake each spring as 4 to 6 inch yearlings [2]. Distribution of these fish during their first year in the lake is poorly known, but they probably move into mid-levels in offshore areas. The following spring they migrate into nearshore waters, but by late spring they again move into deeper water where they remain until late summer; during this period they are pelagic and prefer water temperatures of about 55° F which are usually in the thermocline. Spawning runs to streams are at their peak in September and October when fish are again in shallow inshore waters. Although a large majority of cohos in the lake are stocked, natural reproduction occurs in some tributary streams, at least in the State of Michigan.

Other salmonids

Included here are steelhead or rainbow trout, brown trout and chinook salmon, all of which are important to the sport fishery of

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2/ 18 month old smolts.

Lake Michigan. These fishes are found throughout the lake, but they move into shallow waters during the spring and fall months. They spawn in streams but many fingerlings are released each year in State fish stocking programs; some are released in streams and allowed to migrate to Lake Michigan and the remainder are released in the lake proper. All spawn in the fall except some strains of steelhead which are spring spawners.

Bloater

The bloater is an important commercial species in Lake Michigan. It is the only remaining important species (in Lake Michigan) of a group of species often referred to as "deepwater ciscoes" by biologists and "chubs" by fishermen. It may be found over the entire lake at all depths, but is usually at intermediate depths. Adults are usually on the bottom and young at mid-levels. Spawning occurs January-March in Lake Michigan mostly at depths of 180 to 360 feet. Various early life stages are normally found in or below the thermocline. In summer months, during an upwelling when cold waters invade the beach zone, bloaters may occasionally be found in shallow water; some are also found near shore in winter months. Total length of this fish by the end of its first year of life ranges from 3.5 to 4.5 inches.

Whitefish

No losses of whitefish have been reported at power plant intake screens, but the species is included here because of its importance to the commercial fishery in northern Lake Michigan. This species is most common in the northern third of the lake where few power plants presently exist. Formerly whitefish were abundant throughout the lake and the State of Michigan has instituted management measures to increase abundance in its waters. If these measures are successful, there could be damage to the resource from both thermal pollution at discharges and fish losses at intakes.

Whitefish are found at depths less than 30 feet in spring and fall. Adults spawn in depths of 8 to 15 feet in November and December. Spawning occurs over rock, gravel, or sand that is swept clean by currents. Eggs hatch in late spring and fry can be found in water as shallow as 3 feet until about July 1. After this time, the young gradually move to waters deeper than 30 feet where the temperature is about 62° F (Reckahn, 1970). Young whitefish are less than 2 inches long when they move into deeper waters in early summer. Total length of whitefish at the end of their first year of life is 5 to 7 inches.

Miscellaneous

Other fishes occur in the nearshore waters of Lake Michigan and have been identified from fish collections taken from plant intake screens, but they are less numerous than the aforementioned and most are local in distribution. The once-abundant burbot is now common only in Green Bay, but a few are found in shallow waters in the lake proper. The nine-spine stickleback is most common in northern Lake Michigan, but is becoming more numerous in the south. It spawns near shore in late spring and summer. The johnny darter lives in nearshore waters and at intermediate depths (out to 200 feet), but is most common at depths of 40-100 feet (Unpublished data, Great Lakes Fishery Laboratory). Both the stickleback and darter are small fishes whose maximum length is about 4 inches. White and longnose suckers, carp, black bullheads, channel catfish, gizzard shad, and emerald shiner are generally confined to shallow waters of rivers, near shore areas, and to Green Bay.

B. Zooplankton

Little information is available on the inshore zooplankton of Lake Michigan. Gannon (1972) discussed some zooplankton species of southern Green Bay (which is mostly rather shallow), but did not state the depths at which his samples were taken. Wells (1960 and 1970) mentioned 19 species of cladocerans and 12 species of copepods in offshore areas. Gannon (1972) referred to three other cladoceran species in Green Bay. Available information suggests that with one or two possible exceptions, all these species are also found in the beach zone at some or all times of the year. There are undoubtedly additional species, not reported by the above authors, which are more or less restricted to nearshore waters. Most species reach one population peak each year. Apparently all cladoceran and several species of copepoda overwinter as eggs.

Industrial Bio-Test Laboratories, Inc. (1973a) conducted studies on nearshore planktonic crustaceans in southwestern Lake Michigan from April 1971 to March 1972. They found that copepods composed more than 70 percent of the total zooplankton except in August and September when cladocerans were dominant.

All species migrate vertically to some degree (McNaught, 1966). The vertical movements are influenced mostly by diurnal changes in light intensity. In daytime zooplankton usually avoid surface water but some species may be abundant a few feet below the surface. Migration toward the surface usually begins late in the day. Most species attain their greatest numbers at the surface near sunset and numbers usually decrease near midnight. Most zooplankton are suspended in the water column and will drift with the current. The amount of vertical stratification and diurnal movement of zooplankton in near-shore areas of Lake Michigan is not known.

C. Phytoplankton

Diatoms are the dominant phytoplankton in Lake Michigan. According to Holland (1969) only seven species of diatoms are common. There was an average of 517 diatoms per millileter in the lake and at times of maximum abundance the optimum depth was 5 meters. Numbers were greater in inshore areas than offshore and appreciably higher near the eastern shore than the western shore. Diatoms are planktonic and drift with water currents. Blue-green and green algae are common in polluted areas of southern Lake Michigan and in Green Bay (Schelske and Stoermer, 1970; Beeton, 1969). Studies conducted by Industrial Bio-Test Laboratories, Inc. (1972) in southwestern Lake Michigan suggest that the phytoplankton populations at nearshore sampling stations were generally three-fold higher than those numbers reported by Holland (1969) for stations five miles from shore.

D. Benthos

According to Jarl Hiltunen (Great Lakes Fishery Laboratory) bottom fauna are relatively scarce in the nearshore waters of Lake Michigan except in naturally enriched or polluted areas such as off river mouths and inshore areas in the southern portion of the lake. Bottom animals found within this zone are oligochaetes, chironomids, fingernail clams, and Pontoporeia. In grossly polluted areas oligochaetes will dominate and Pontoporeia will be absent.

Industrial Bio-Test Laboratories, Inc. (1973a) conducted studies on bottom fauna in southwestern Lake Michigan near the Waukegan and Zion Generating Stations. They found that the average number of benthic organisms per ponar grab was 83 at 3 meters, 238 at 6 meters, 358 at 9 meters, and 306 at 12 meters. They also found that Pontoporeia was the most abundant benthic organism followed by oligochaetes, pelecypods, chironomids, and gastropods.

Effects of Water Intakes

A. Mortalities caused by impingement of fish on intake screens

Estimates of the numbers of fish drawn into plant cooling systems and impinged upon screens are only now becoming available for Lake Michigan. Most utilities will or are now in the process of documenting the species, number, and sizes of fish removed from their intake screens.

Edsall and Yocom (1972) compiled what they considered to be an incomplete listing. Some of their findings are given in the following paragraphs.

One of the earliest reports of a fish kill at water intakes in Lake Michigan is a description of the alewife problem at the Waukegan generating station at Waukegan, Illinois (Danson, 1967). This report described the sometimes massive impingement of alewives on the plant's vertical traveling screens. Fish were impinged May 18-June 18, 1961; May 7-11, 1962; for an unstated period in 1963 beginning on May 6; and May 5-July 11, 1964. The chlorination of the intake water was apparently responsible, in part, for the massive impingements that occurred on certain dates. Further kills were reported in 1965 and 1966 (Sally W. Jones, Chicago Tribune, letter of August 11, 1972, to T. Edsall). In 1965, alewives jammed the intake of the Waukegan power plant and caused a large generator to burn out (Chicago Tribune, issue of February 8, 1966); and on April 27, 1966, so many alewives entered the Waukegan plant that one 204,000-kilowatt generating unit had to be shut down completely and two others operated at only 50 percent capacity.

Alewives have also been reported entering water intakes of two steel companies (Sally W. Jones, letter of August 11, 1972, to T. Edsall). They entered the intakes of U.S. Steel Corporation's Gary (Indiana) Works in spring 1966 in sufficient numbers to sink a net strung across the mouth of the intake; a steel cable was finally required to resuspend the net. Inland Steel Company's Indiana Harbor Works has also experienced difficulty with fish (presumably alewives) and at times has had to shut down all 12 condensers at their Lake Michigan pumping station to rid them of fish. Inland Steel reduced the severity of the kills by installing a net across the pumping station inlet.

Operating records on file at the Chicago Central District Water Filtration Plant indicate occasional heavy fish kills there and at the South Plant. During April and May 1965 as many as 30,000 pounds of adult alewives (about 450,000 fish) per hour were removed from the vertical traveling screens of the Central District Plant during daily peak periods. Alewives also have repeatedly clogged the water intake screens at the South Filtration Plant, where a total of 407,000 pounds of fish were removed from 1965 through 1972. Fish loads usually reached a maximum during early May, except in 1969 when the peak was on July 21. The annual kill ranged from 21,000 pounds (about 315,000 fish) in 1965 to 123,000 pounds (1,845,000 fish) in 1971 and averaged about 51,000 pounds (about 765,000 fish) per year.

A study conducted by the U.S. Environmental Protection Agency (1972) in November 1971, to determine the rate at which eggs of lake whitefish and lake trout were drawn into the cooling water intake of Big Rock Power Plant at Charlevoix, Michigan, revealed that "many ripe male lake trout" were drawn into the intake of this plant. The actual number of lake trout observed in the intake forebay was not given nor was the fate of these fish discussed. Several fish were taken in a pumping device used to sample the intake water for fish eggs, but the 3-inch diameter suction hose used for sampling was probably highly unsuitable for collecting fish. Nevertheless, the one longnose sucker and two chubs (bloater) captured on November 9 represented a potential 24-hour plant intake of about 150 suckers and 300 chubs.

A continuation of this study at the Escanaba (Michigan) Power Plant, November 30-December 4, 1971, resulted in a catch of 37 smelt on November 30. Expansion of this number to include the total inflow suggested that about 1,000 smelt were drawn into the plant during the 8-hour sampling period on November 30 and that about 3,000 smelt could have been taken into the plant during the 24 hours of plant operation encompassing that sampling date. Since the data in the Environmental Protection Agency report did not include the size of the suckers, chubs, and smelt taken in the Big Rock and Escanaba sampling operations, we were unable to determine whether these fish were large enough to have been impinged on the plant screens.

A massive fish kill caused by impingement on screens and clogging of condensers occurred in late January and early February 1971 at the Consumer Power Company's Campbell plant on the eastern shore of Lake Michigan (Memorandum from J. Truchan, Michigan Water Resources Commission to F. B. Frost et al., February 17, 1971). Michigan Water Resources Commission personnel investigating the incident determined that: (1) the kill, first reported to them on February 4, had been in progress for the previous 7 to 10 days; (2) several hundred thousand fish had been killed by impingement; (3) these fish were mostly gizzard shad, but alewives and yellow perch were also killed; (5) the dead fish had been discharged into the outlet canal and washed back into Lake Michigan; (5) dead fish were not visible in the 10 to 20 acres of ice-free open water around the mouth of the discharge canal on February 4; (6) similar problems of fish impingement on the plant's traveling intake screens have occurred in other winters; and (7) on these occasions the fish were also disposed of in the discharge canal. The problem was attributed to the recirculation of warm effluent water to prevent ice formation at the intake. An area of warm water more than a mile long was created, which apparently acted to attract fish into the area where they could be drawn into the plant.

Information on impingement of fish on the intake screens of the Palisades power plant in southeastern Lake Michigan (near South Haven, Michigan) in 1972 was made available upon request to the Environmental Protection Agency by the Consumers Power Company. A portion of the information was also presented at the 1972 annual meeting of the American Fisheries Society on September 10 by Dr. Robert Benda, Biology Department, Aquinas College, Grand Rapids, Michigan (Benda, 1972).

Fish were collected from the screens during two periods by different workers. Data were collected by plant maintenance personnel with the assistance of the company's aquatic biologist from January 23 to May 15, 1972 (Consumers Power Company, 1972). During this 114-day period, 2,220 fish of 14 species were removed from the intake screens of the plant. Among these were 967 alewives, 227 sculpins (presumably slimy sculpins), 103 yellow perch, 68 smelt, 5 lake trout, 11 rainbow trout, 2 coho and 1 chinnok salmon (Table 2). Subsequent collections were made by Consumer Power Company's environmental study personnel (Presumably including Dr. Benda), who were stationed at the site from May 16 to August 25 (Benda, 1972). In this 102-day period, a total of 51,250 fish of 21 species were removed from the plant screens. Included were 28,272 alewives, 8,608 yellow perch, 7,343 slimy sculpins, 4,738 spottail shiners, 748 trout-perch, 610 smelt, 13 salmon, 14 lake trout, and 1 brown trout (Table 2).

Some of the fish were partly decomposed and were apparently dead before they were drawn into the plant; most of the others which were presumably drawn into the plant alive, had suffered mechanical damage ranging from open wounds to descaling and hemorrhaging, and some of these were dead when they were removed from the plant screens.

Table 2 --
Total number of fish collected from traveling screens at the Palisades Nuclear Generating Plant during three time periods January 23 to August 25, 1972. (Total length in inches shown in parenthesis)

	Collection period			
Species	1/24-5/15[1]	5/16-7/01	7/02-8/25	Total
Bowfin	54(13-20)	0	0	54
Alewife	967(1- 6)	13,082(2-10)	15,190(2-10)	29,239
Chinook salmon	1(22)	0	1(33)	2
Coho salmon	2(23)	11(6-19)	1(6)	14
Lake trout	5(16-28)	13(6-16)	1	19
Brown trout	0	0	1(10)	1
Rainbow trout	11(6-14)	0	0	11
Bloater	2(3- 6)	197(4- 9)	134(4-10)	333
Smelt	68(3- 8)	530(2-10)	80(3-12)	678
White Sucker	0	5(8-16)	9(8-22)	14
Longnose sucker	45(4-24)	64(8-20)	143(8-24)	252
Carp	14(3-10)	0	0	14
Longnose dace	0	3	0	3
Spottail shiner	0	3,955(2- 6)	783(2- 6)	4,738
Channel catfish	1(8)	11(4- 6)	6(6-10)	18
Black bullhead	0	25(3- 4)	4(6- 8)	29
Burbot	20(8-24)	26(12-24)	18(8-22)	64
Trout-perch	0	543(2- 6)	205(2- 6)	748
Yellow perch	103(3-12)	6,262(2-16)	2,346(4-14)	8,711
Johnny darter	0	10(1- 2)	0	10

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[1] Data may not be comparable to other sampling periods because of sampling techniques.

Table 2, continued

	Collection period			
Species	1/24-5/15[1/]	5/16-7/01	7/02-8/25	Total
Bluegill	0	1(2)	0	1
Rock bass	0	1(7)	0	1
Slimy sculpin	927(1- 5)	7,178(1- 4)	165(2-5)	8,270
Nine-spine stickelback	0	231(1- 3)	15(2-4)	246
Total	2,220	32,148	19,102	53,470

The plant was in almost continuous operation from May 16 to August 25 with an intake flow of 405,000 gpm (Benda, 1972) and the numbers of fish removed from the plant screens were probably representative of fish living in the area of the plant intake during that portion of the year. Evaluation of the kill data for January 23 to May 15 is difficult, however, because information on the volume of water pumped through the plant cooling system was not given. There is suggestion that sampling techniques differed between sampling periods and therefore interpretation of these data was not attempted.

The sampling period of May 16 to August 25 coincided reasonably well with the periods of heavy or peak abundance of bloaters, smelt trout-perch, adult yellow perch, and spottail shiner in water 18 to 30 feet deep in southeastern Lake Michigan, as shown by Wells (1968). The peak abundance of slimy sculpins, however, occurs in February through mid-April at the 18- to 30-foot depth range (Wells, 1968); consequently, the large catch of sculpins reported by Benda (7,343 fish with the peak catch in early June) suggests that extremely heavy annual entrainment mortality could be expected for this species, with peak impingement occurring during the winter and early spring at the Palisades plant.

A substantial portion of the time of heavy to peak abundance of adult alewives (age I and older) in water 18 to 30 feet deep in southeastern Lake Michigan also precedes the sampling period reported by Benda (1972). The data of Wells (1968) show that adult alewives were scarce or absent at these depths on March 11, but reached nearly peak abundance for the entire year on April 15 and May 5.

Heavy annual entrainment mortality of alewives can be expected to occur at the Palisades plant beginning about April 15. This expected pattern of entrainment did occur at the State Line Generating Station near Gary, Indiana (Table 3).

The times of peak abundance for species other than those by Wells (1968) in water 18 to 30 feet deep in southeastern Lake Michigan have not been well documented; the available information indicates, however, that burbot, lake herring, lake whitefish, and most trout and salmon can be expected to become more abundant at these depths in the fall than in other seasons. Spawning lake trout were shown to be abundant near the intakes of the Palisades and Book generating plants in the fall of 1971 (report for cruise XII, R/V *Kaho*, November 16 to December 2, 1971 and report for cruise XII, R/V *Cisco*, November 16 to December 4, 1971, Great Lakes Fishery Laboratory). The collection of a 13-pound chinook salmon on the Palisades plant's screens (Benda, 1972) suggests that the entrainment of adult lake trout is a possibility, especially during the spawning season when they are abundant in the area of the plant intake.

Table 3 -- Daily and estimated weekly number and total length range (inches of each species of fish identified from collections taken from the traveling screens at the State Line Generating Station (April 28 to September 8, 1972.

Date	Alewife	Yellow perch	Smelt	Gizzard shad	Carp
	a b				
4/28	3,525(24,675)		35(245)		
5/05	9,472(66,304)	1(7)	56,392)		
5/12	12,080(84,560)	2(14)	50,350)		6(42)
5/19	11,175(78,225	10(70)		2,775(19,425)	
5/26	3,500(24,500)			3,500(24,500)	3(21)
6/02	1,832(12,824)	2(14)		920(6,440)	1(7)
6/09	1,300(9,100)			20(140)	1(7)
6/16	6,137(42,959)	7(49)		1,587(11,109)	4(28)
6/23	2,575(18,025)	3(21)		200(1,400)	
6/30	2,900(20,300)	26(182)			
7/07	2,900(20,300)	14(98)			
7/14	700(4,900)	8(56)			2(14)

a 24-hour count once each week.

b ( ) estimated weekly = 24-hour count x 7.

Table 3, Continued
Daily and estimated weekly number and total length range (inches of each species of fish identified from collections taken from the traveling screens at the State Line Generating Station (April 28 to September 8, 1972.

Date	Alewife	Yellow perch	Smelt	Gizzard shad	Carp
	a b				
7/20	250(1,750)	17(119)			1(7)
8/06	100(700)	11(77)			2(14)
8/11	30(210)	5(35)			1(7)
8/18	234(1,638)	16(112)			2(14)
8/25	131(917)	15(105)			
9/01	246(1,722)	6(42)			4(28)
9/08	56(392)	5(35)			2(14)

As mentioned earlier, entrainment of spawning lake trout was documented at the Big Rock generating plant, Charlevoix, Michigan (U.S. Environmental Protection Agency, 1972).

Additional data on mortalities caused by impingement of fish on intake screens have become available since Edsall and Yocom (1972) prepared their report. The most numerous fishes collected from the Palisades plant traveling screen, January 24 to December 29, 1972, are shown in Table 4. Smelt, yellow perch, and slimy sculpin were most common during the period May 16 to August 25. Alewives, spottail shiner, and longnose sucker were most common between August 26 and December 29. Most alewives taken during this latter period were young-of-the-year; largest numbers were taken in October. This was to be expected since Wells (1968) found that age 0 alewife were common in nearshore waters during October.

Loss of fish during 1972 at the State Line Generating Station located in extreme southern Lake Michigan and at the Waukegan Generating Station in southwestern Lake Michigan were furnished to the Environmental Protection Agency by the Commonwealth Edison Company. These data were collected by station personnel and fish surveys were made once each week for a 24-hour period. Biologists did not participate directly in the counts and therefore the data may not indicate the actual number of each species removed because of lack of species identification. Tables 3 and 5 list the number of fish obtained for each 24-hour collection period at the State Line and Waukegan plants, respectively. Estimates of the total number of fish lost during each sample week were obtained by multiplying the 24-hour count by 7.

Table 4 -- Total number of major fish species collected from traveling screens of the Palisades Nuclear Generating Station during three time periods, January 24 to December 29, 1972

Collection period	1/24-5/15[1]	5/16-8/25	8/26-12/29[2]
Weeks sampled	16	15	18
Species			
Alewife	967	28,272	42,150[3]
Smelt	68	610	215
Longnose sucker	45	207	295
Spottail Shiner	0	4,738	18,715
Yellow perch	103	8,608	2,940
Slimy sculpin	927	7,343	560

1/ Data may not be comparable to other periods because of different sampling techniques.

2/ Numbers slightly in error because data were taken from graph.

3/ Most were age 0.

Five species totaling 68,463 individuals were collected in nineteen 24-hour sampling periods from April 28 to September 9 at the State Line Generating Station (Table 3). The estimated number of fish impinged during the study period was 479,241. Alewives were most common in collections (86 percent) followed by gizzard shad (13 percent), yellow perch, smelt, and carp.

Eleven species totaling 30,537 fish were collected in thirteen 24-hour sampling periods from June 15 to September 7 at the Waukegan Generating Station (Table 5). The estimated number of fish impinged during the study period was 213,759. Alewives comprised 98 percent of the collection.

Table 5 --

Daily and estimated weekly number and total length range (inches) of each species of fish identified from collections taken from the traveling screens at the Waukegan Generating Station (June 15 to September 7, 1972

Date	Alewife	Yellow perch	Smelt	Trout1/	Bluegill	Gizzard shad	Emerald shiner	Carp	Carp-sucker2/	Black bullhead
	a b									
6/15	4,041(28,287)		1(7)	1(7)		6(42)		3(21)		
6/22	3,055(21,385)			3(2)			8(56)			11(77)
6/29	2,784(19,488)	2(14)	1(7)							
7/06	4,503(31,521)									
7/13	2,601(18,207)						15(105)			
7/20	2,853(19,971)	2(14)	269(1,883)					1(7)		
7/27	1,862(13,034)	2(14)		2				20(140)	2(14)	
8/03	1,118(7,826)	3(21)		1(7)		26(182)				
8/10	1,146(8,022)		1(7)	1(7)	1(7)			1(7)		
8/17	3,856(26,992)	1(7)						6		
8/24	1,625(11,375)	3(2)	2(14)							
8/31	508(3,556)	1(7)				23(161)		4(28)	1(7)	
9/07	160(1,120)		1(7)					1(7)	1(7)	
Total Number	30,112(210,784)	13(91)	275(1,925)	8(56)	1(7)	55(385)	23(161)	34(238)	5(35)	11(77)
Length range	3-8	5-6	2-8	4-30	4	5-7	2-6	8-30	10-18	3-6

1/ Includes both coho salmon and trout.

a. 24-hour count once each week.

b. ( ) estimated weekly - 24-hour count x 7.

2/ Probably white sucker.

The Environmental Protection Agency was furnished limited information on fish kills on traveling screens at other generating stations. At the DeYoung plant in southeastern Lake Michigan, alewives, carp, and shinefs have been observed by plant personnel. The Edgewater plant near Sheboygan, Wisconsin in western Lake Michigan reported adjective estimates of fish losses in intakes. Alewives are frequently killed, gizzard shad only occasionally, and smelt, carp, and lake trout rarely. The Kewaunee plant near Kewaunee, Wisconsin in northwestern Lake Michigan has not yet become operational. In preliminary testing in August and September, 1972 fish losses on traveling screens were recorded but only those exceeding 6 inches in length excluding alewives were measured, weighed and identified. Number of each species listed was as follows:

Species	Number	Length range
Alewife	--------No data----------------	
Yellow perch	57	6-10 inches
White sucker	16	8-15 inches
Carp	2	9-12 inches
Bullhead	1	11 inches

The Pulliam plant at the south end of Green Bay reports they have a bubble screen that is effective at restraining mass influx of schooling fish into their intake structure. To our knowledge no data are available on the kinds and numbers of fish entrained prior to and following the installation of the bubble screens. On occasion, alewives and bullheads have caused serious problems with the operation of traveling screens at this plant.

B. Mortality of organisms too small to be impinged on intake screens.

Many Lake Michigan fish species spawn within the beach water zone and eggs of some are pelagic and drift with the water currents. Other fishes spawn in tributary streams and larvae are carried by currents to the lake and into the nearshore zone. Currents near shore can occur naturally because of wind or artificially because of water withdrawal by intake structures. Pelagic life stages are too small (usually less than 1 inch long) to be impinged on traveling screens and they are carried through the plant with the cooling water. It is also probable that most fish less than 2 inches long also pass through the 3/8-inch mesh of the traveling screen because they are too small or soft-bodied to be impinged and too weak to avoid the currents created at the intake by water withdrawal. Most fish found on the traveling screens are 3 inches in length or longer (Tables 2, 3, and 5). Earlier in this report we have pointed out that young (fish less than 3 inches long) of many species are known to occur near shore or within the 30-foot contour. Other organisms in the inshore zone too small to be impinged on the screens are zooplankton, phytoplankton, and certain bottom fauna with mobile life stages.

According to Edsall and Yocom (1972) fish and other organisms small enough to pass through the 3/8-inch mesh traveling screen and the condensers encounter a wide range of additional stresses during their passage through the rest of the plant cooling system. They may be damaged or killed by: (1) collision with the internal surfaces of the cooling system, including the traveling screens, pump impellers, and the heat exchanger surfaces; (2) thermal stress caused by the heat added to the cooling water during passage through the heat exchanger; (3) gas bubble disease or the formation of air embolisms caused by pressure and temperature changes in the cooling system; and (4) exposure to chlorine and other biocidal chemicals used to clean cooling system surfaces. The stresses encountered during passage through a plant, when not fatal, may have severe debilitating effects on the entrained organisms and cause their normal life processes to be disrupted for a significant period of time after they leave the plant cooling system.

Fish: eggs, larvae, young-of-the-year

Edsall and Yocom (1972) cite studies at power plants located on rivers and tidal areas where large numbers of fish eggs and larvae have been killed in passage through power plant cooling systems. They found little information on the kinds and numbers of fish eggs and larvae that are passed through cooling systems of Lake Michigan generating stations. They did report on a study conducted at the Point Beach (Wisconsin) Generating Station from March 3 to May 27, 1971 and from November 4, 1971 to March 3, 1972. A similar study was conducted at the Oak Creek (Wisconsin) Generating Station from March 22 to April 22, 1971.

Eight sculpin and a few smelt eggs were collected at Point Beach in 1971. From the ratio of water sampled through plankton nets to that passed through the power plant, Edsall and Yocom (1972) estimated that more than 4 million sculpins could have passed through the plant cooling system between March 3 and April 29. It was also estimated that more than 400,000 smelt eggs could have passed through the plant in one 24-hour period. The possible entrainment of large numbers of sculpins (presumably slimy sculpins) during late winter and early spring is consistent with the data of Wells (1968), which shows that late winter and early spring should be the time of greatest abundance of this species at the water depth at which the Point Beach water intake is located. Edsall and Yocom (1972) also reported that smelt and smelt eggs were collected from the intakes at Oak Creek in April 1972, but they were unable to estimate total numbers lost. Smelt eggs were reported as "numerous" in samples.

Benda (1972) sampled the Palisades Generating Station intake bay for 142 hours between May 17 and June 22, 1971 with a plankton net. He collected 918 eggs and 4 larvae, none of which was positively identified. The methods used by Benda to estimate numbers of fish eggs and larvae passing through the power plant appear grossly inadequate. This same opinion was expressed by Edsall and Yocom (1972).

Industrial Bio-Test Laboratories, Inc. (1973b) conducted studies at the Waukegan Generating Station in southwestern Lake Michigan to determine loss of phytoplankton in once through cooling. Samples were collected in the discharge canal six times each month from April through December 1971 with a 1/2-meter plankton net with #6 (239 microns) nylon mesh. Only three fish larvae were found in the phytoplankton samples; two were from the sunfish family and one was unidentified.

Waukegan has an onshore intake while the stations mentioned in the preceding paragraphs have offshore intakes.

Because of limited studies on Lake Michigan, we have little positive information concerning the loss of fish eggs and larvae in waters withdrawn for various purposes such as municipal water supply, industrial use, or cooling water. Studies conducted by the Great Lakes Fishery Laboratory along the eastern shore of Lake Michigan in 1972, however, suggest the potential for loss of young fish is great.

Sampling was conducted with 1/2 meter diameter plankton nets (351 micron mesh) at 10 stations between the Michigan-Indiana boundary and Frankfort, Michigan.[3/] Samples were taken between May 3 and August 30. Depth on station was 18 and 30 feet (also 24 feet in May and June); sampling depths extended from the surface to 14 or 20 feet dependent on station depth. Fry of alewife, perch, smelt, coregonids (probably bloater) and trout-perch were identified in samples; the latter two species were uncommon. The maximum number of fry collected at individual stations per 1,000 cubic meters of water sampled ranged from 2,700 to 20,000 for alewife, 10 to 1,000 for yellow perch, and 0 to 40 for smelt.

Smelt fry were most abundant in May, yellow perch in June and early July, and alewives in July and August. Difference in times of fry appearance in samples and times of peak abundance are in agreement with information on the spawning and hatching times for these species inLake Michigan, which indicates that smelt should have appeared first

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[3/] Wells, LaRue. Distribution of fish fry in nearshore waters of southeastern and east central Lake Michigan, May-August, 1972. Great Lakes Fishery Laboratory, Administrative Report, January 1973.

followed by perch and finally alewives. The abundance of fry in nearshore areas during spring and summer months clearly illustrates the potential lake for cooling or other purposes. The few numbers of small fish collected from the cooling waters of the plants cited in this report may be the result of poor sampling techniques.

Zooplankton

Data on the effects of passage of zooplankton through power plants are difficult to evaluate but some general trends have emerged. According to McNaught (1972) the greatest mortality in zooplankton passing through power plant cooling systems is caused by mechanical or abrasive damage. In a study at the Waukegan plant, he found that mortality due to abrasion varied from 3.1 percent when small zooplankters were most abundant in his samples to 11 percent when larger zooplankters were most abundant. During the period of the study, an average of only 0.7 percent of the zooplankton passing through the plant was killed by thermal stress. The higher mortality from mechanical effects was observed because lethal temperatures were not reached during passage through the plant. However, in other studies where lethal temperatures have been reached, mortalities of zooplankton have exceeded 80 percent, and only 7-10 percent of the total was attributed to abrasion (Coutant, 1970). Milburn (1972) estimated that 100 percent of the zooplankton passing through the J. M. Stuart Generating Station during July and August was killed by heat effects alone when discharge temperature reached 95-99° F. Mortalities of 29-55 percent recorded at the Big Rock Generation Station during November and December 1971 were attributed to both mechanical and thermal damage that occurred during passage through the plant (Grosse Ile Laboratory, 1972).

Zooplankters that survive passage through plant cooling systems often suffer serious sublethal effects. Heinle (as cited by Coutant, 1970) found that populations which had experienced thermal and mechanical shocks during passage through the plant had reduced reproductive potential even when the exposure temperatures were below the laboratory-determined lethal temperatures. He also found that zooplankton which survived chlorination had reduced reproductive potential.

Phytoplankton

The effect of entrainment of planktonic algae (diatoms) in once-through cooling systems is not completely understood. Benda (1972) reported on studies he conducted at the Palisades Generating Station. Carbon 14 tests were conducted to determine if any loss of phyto-synthetic activity occurred as a result of the once-through cooling process. Phytosynthetic activity in the samples varied from a gain of 105 percent in the discharge over the intake sample to an 81 percent loss in the discharge over the intake water. The results were not consistent and showed considerable variation. Out of 12 tests conducted on a heated discharge, three showed more activity or no loss in activity in the discharge sample when compared to the intake sample, but the majority (9 of 12) showed losses in activity ranging from 11 to 79 percent. Tests were also conducted when no heat was being added and one of the two tests showed no loss in activity in the discharge sample, while the other showed a loss of 13 percent.

Industrial Bio-Test Laboratories, Inc. (1973b) found that phytoplankton subjected to condenser passage with an increase in temperature of 20° F at the Waukegan Generating Station exhibited inhibition in photosynthesis related to temperature of the intake and duration of storage of the samples incubated with Carbon 14. No differences in Carbon 14 uptake after 75 hours of storage were found between intake and discharge samples when the intake temperature was below 46° F unless recirculation was being conducted to keep the intake ice free. When intake temperatures were above 46° F, an average reduction in photosynthetic rates was found to be 28 and 42 percent after 51 and 75 hours of storage, respectively. Although photosynthetic rates decreased, a decline in chlorophyll a concentration did not occur. Bio-Test concluded that the reduced photosynthetic capacity per unit of chlorophyll suggested metabolic impairment of phytoplankton due to condenser passage when intake temperatures were above 46° F

Benthos

Major groups of bottom fauna found in the beach water zone are oligochaetes, chironomids, fingernail clams, and Pontoporeia. Oligochaetes and fingernail clams remain in the bottom but chironomid larvae and the amphipod Pontoporeia move off the bottom. These forms are particularly active at night. Movements increase from spring to summer and decrease in the fall. Although these forms are generally not abundant near shore, there is potential for some loss due to entrainment.

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LITERATURE CITED

Beeton, A.M. 1969. Changes in the environment and biota of the Great Lakes, p. 150-187. In Eutrophication: causes, consequences, correctives. Nat. Acad. Sci. Publ. 1700.

Benda, R.S. 1972. Thermal effects studies at the Palisades Nuclear Plant, preliminary findings from the first few months of operation. Presented at Annual Meeting of American Fisheries Society, Hot Springs, AR., Sept. 10, 1972.

Consumers Power Company. 1972. Palisades plant, special report, environmental impact of plant operation up to July 1, 1972. Filed with: U.S. At. Energy Comm., July 19, 1972.

Coutant, C.C. 1970. Biological aspects of thermal Pollution. I. Entrainment and discharge canal effects. Chemical Rubber Company Critical Reviews Environ. Contr. 1(3): 341-381.

Danson, J.O. 1967. Alewife problems at Waukegan Generating Station. J. Amer. Water Works Assn. Jan. 1967, p. 114-119.

Edsall, T., and T. Yocom. 1972. Review of recent technical information concerning the adverse effects of once-through cooling on Lake Michigan. Great Lakes Fishery Laboratory, Ann Arbor, Mich.

Ferguson, R.G. 1965. Bathymetric distribution of American smelt Osmerus mordax in Lake Erie. Great Lakes Res. Div., Univ. Mich. Publ. 13: 47-60.

Gannon, J.E. 1972. Effects of eutrophication and fish predation on recent changes in zooplankton crustacea species composition in Lake Michigan. Trans. Amer. Micros. Soc. 91(1): 82-84.

Grosse Ile Laboratory. 1972. Lake Michigan entrainment studies, Big Rock Nuclear Power Plant, Escanaba Power Plant, November-December 1971. E.P.A. Office of Research and Monitoring, Grosse Ile, Michigan. Rep. 1.

Holland, R.E. 1969. Seasonal fluctuations of Lake Michigan diatoms. Limnol. Oceanogr. 14: 423-436.

Industrial Bio-Test Laboratories, Inc. 1972. Inshore water quality evaluation. Project II, Part B - Phytoplankton, May 1970-March 1971. In Report to Commonwealth Edison Company, Chicago, Illinois, "Evaluation of thermal effects in southwestern Lake Michigan (January 1970-April 1971)".

Industrial Bio-Test Laboratories, Inc. 1973a. Field study program of Lake Michigan in the vicinity of the Waukegan and Zion Generating Stations. Project X. In Report to Commonwealth Edison Company, Chicago, Illinois, "Evaluation of thermal effects in southwestern Lake Michigan (April 1971-March 1972)".

Industrial Bio-Test Laboratories, Inc. 1973b. Intake discharge experiments at the Waukegan Generating Station. Project XI. In Report to Commonwealth Edison Company, Chicago, Illinois, "Evaluation of thermal effects in southwestern Lake Michigan (May 1971 - April 1972)".

McNaught, D.C. 1966. Depth control by planktonic cladocerans in Lake Michigan. Pub. No. 15. Great Lakes Research Division, Univ. Mich.

McNaught, D.C. 1972. The potential effects of condenser passage on the entrained zooplankton at Zion station. Prepared statement at Lake Michigan Enforcement Conf., Sept. 21, 1972, Chicago, Illinois.

Milburn, G.S. 1972. Statement in the matter of J.M. Stuart Power Station. U.S. Environ. Prot. Agency. Chicago, Illinois.

Reckahn, J.A. 1970. Ecology of young lake whitefish (*Coregonus clupeaformis*) in South Bay, Manitoulin Island, Lake Huron. *In*: C.C. Lindsey and C.S. Woods (ed.) Biology of coregonid fishes. p. 437-460, Univ. of Manitoba Press, Winnipeg, Manitoba, Canada.

Schelske, C.L., and E.F. Stoermer. 1970. Depletion of silicon and accelerated eutrophication in Lake Michigan. Abstr. Pap. 33rd Annu. Meet. Amer. Soc. Limnol. Oceanogr. (unpaged).

U.S. Department of the Interior. 1970. Physical and ecological effects of waste heat on Lake Michigan. Great Lakes Fishery Laboratory, Ann Arbor, Michigan. (processed).

U.S. Environmental Protection Agency. 1972. Lake Michigan Entrainment Studies. Big Rock Nuclear Power Plant - Escanaba Power Plant. Grosse Ile Laboratory Environmental Protection Agency, 9311 Groh Road, Grosse Ile, Michigan 48138.

Wells, L. 1960. Seasonal abundance and vertical movements of planktonic crustacea in Lake Michigan. U.S. Fish Wildl. Serv., Fish. Bull. 60: 343-369.

Wells, L. 1968. Seasonal depth distribution of fish in southeastern Lake Michigan. U.S. Fish. Wildl. Serv., Fish. Bull. 67(1): 1-15.

Wells, L. 1970. Effects of alewife predation on zooplankton populations in Lake Michigan. Limnol. Oceanogr. 15: 556-565.

APPENDIX D

Water Intake Information For Lake Michigan

by

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Summary

A brief summary of information from all the municipal, industrial and utility water intakes in Lake Michigan is presented below:

	No. of facilities	Water used (cfs)	Number of Intakes		Average intake velocity (fps)	
			Offshore	Shoreline	Offshore	Shoreline
Municipalities	45	4,011	91	9	0.95	----
Industrial	19	4,974	17	13	1.40	1.76
Utilities	21	21,881	15	13	1.30	2.00
Total	85	30,866	123	35	----	----
Average	--	------	---	--	1.22	1.88

A total of 85 facilities withdraw water from Lake Michigan. These facilities assuming full operation withdraw approximately 31,000 cfs of water. The majority of intakes (78%) are located offshore and have an average intake velocity at the crib of slightly over one foot per second (1.2 fps). The shoreline intakes have a considerably higher intake velocity averaging almost 2 feet per second (1.88 fps).

Very little quantitative information was provided concerning loss of fish at these facilities. Thirty-four percent of the facilities, however, did include fish as part of the material removed from the intake screening systems. Screening devices which could protect fish were reported on municipal, industrial and utility intakes. These devices include: rock filled cribs, air bubbler screens, electric screens, fish deflectors and nets. No modifications which would allow for the safe removal or bypass of fish life were utilized in screening systems in the forebay area. The fine mesh screens are invariably positioned perpendicular to water flow with entrapped fish and debris removed during cleaning operations.

Municipal Water Intakes

To obtain current operating and design information on water intakes in Lake Michigan, questionnaires were sent to 45 municipalities with intakes in Lake Michigan. Of the 45 municipalities sent questionnaires 42 (94%) responded with the information requested. The results were tabulated by state and municipality and are presented as Attachment I.

Table 1 is a brief summary of some basic information for municipal intakes in each of the states.

Table 1. Summary data for municipalities withdrawing water from Lake Michigan.

	No. Municipalities	Total water withdrawal (cfs)	No. intake structures in lake	No. intakes offshore	Average distance offshore (feet)
Michigan	18	415	21	16	3,561
Indiana	3	1,206	9	8	4,338
Illinois	11(1)	1,816	17	15	4,551
Wisconsin	13	574	53	52	4,357
TOTAL	45	4,011	100	91	--
Average	--	--	--	--	4,202

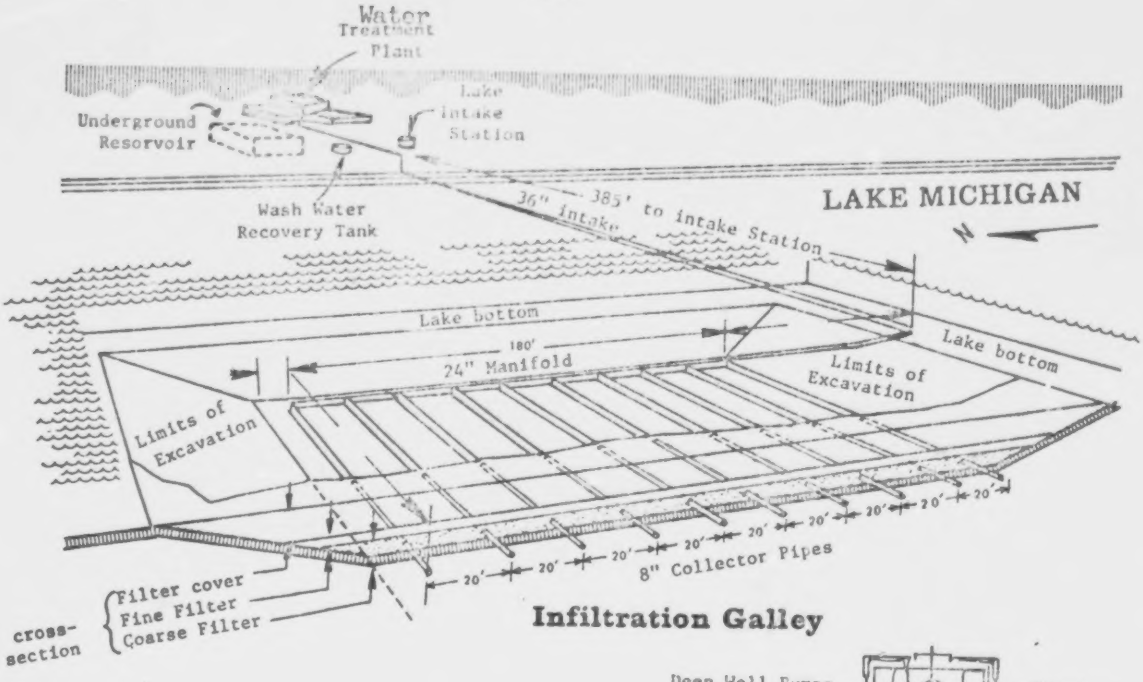
(1) Three did not return questionnaire and are not included in subsequent calculations.

Michigan reported the largest number of intakes (18) with Wisconsin second with 13 followed by Illinois (11) and Indiana (3). However in terms of water withdrawal, Illinois uses the largest amount of water 1,816 cfs (cubic feet per second) followed by Indiana (1,206 cfs), Wisconsin (574 cfs) and Michigan (415 cfs). The total amount of water which could be withdrawn from Lake Michigan by all municipal sources is approximately 4,000 cfs. Of this total the city of Chicago, Illinois makes up approximately 41% or 1,561 cfs.

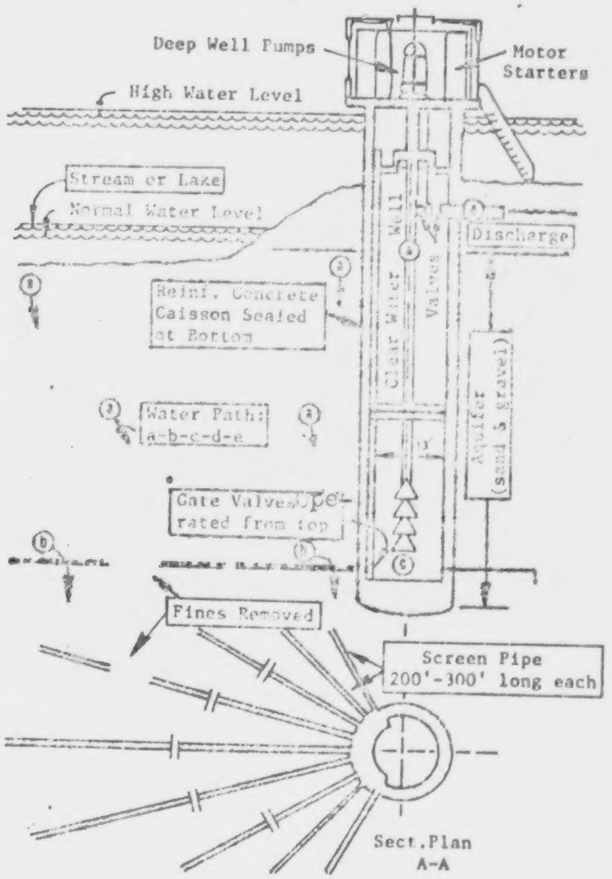
The majority (91%) of municipal intakes on Lake Michigan are the offshore type with the point of water withdrawal about 4,000 feet from shore. The only shoreline intake reported was for the city of Chicago. Other municipalities with shoreline intakes used either infiltration galleries or radial collectors, both of which draw water through an artificial aquifer or the lake bottom but not directly from the lake (Figure 1).

Generally the offshore intakes have some type of crib structure surrounding the end of the intake conduit. The crib structures range widely in size, design, shape and construction with few common characteristics. Figures 2, 3 and 4 illustrate the range of intake cribs reported in use. One intake (Kenosha, Wisconsin) employs an open pipe with no special crib structure. Several facilities did not report cribs as such but did indicate a fine mesh screening sleeve in place over the end of the conduit (Figure 5). Water intake openings in the cribs ranged in size from one inch up to twelve inches with several cribs having open systems. Water velocities at the mouth of the intake cribs ranged from 0.1 to 6.0 fps (feet per second) with the average velocity slightly less than one foot per second (0.95 fps).

The design and operation of municipal water intakes utilized in Lake Michigan is extremely variable. The majority of intakes however, do employ fine mesh screens located in a forebay area to remove fish, vegetation and debris from the incoming water. There is no uniform size screen opening but, screens with 3/8 inch openings were most frequently reported. The screens are generally stationary, positioned perpendicular to water flow and are manually removed for cleaning. Some

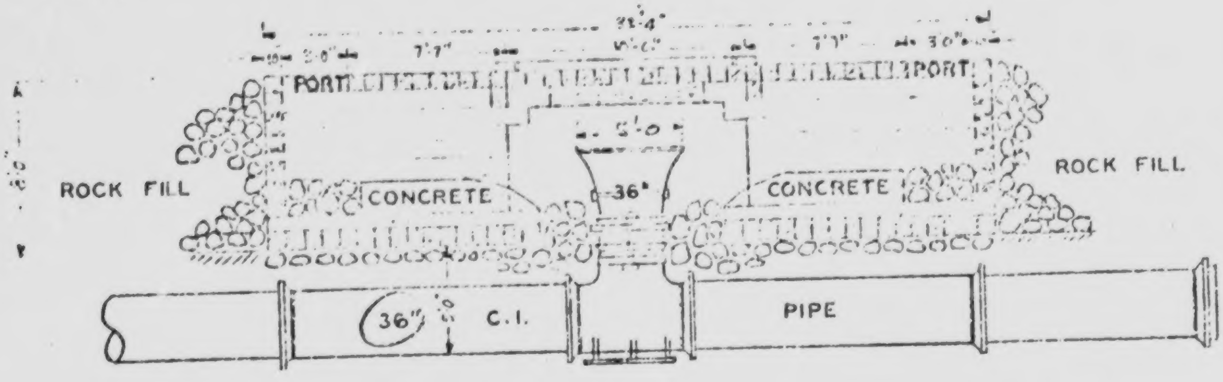

Water Treatment Plant
Underground Resorvoir
Lake Intake Station
Wash Water Recovery Tank
36" intake
385' to intake Station
LAKE MICHIGAN
N
Lake bottom
Lake bottom
180'
24" Manifold
Limits of Excavation
Limits of Excavation
20'
20'
20'
20'
20'
20'
20'
20'
20'
20'
8" Collector Pipes
Filter cover
Fine Filter
Coarse Filter
cross-section

Infiltration Galley


Deep Well Pumps
Motor Starters
High Water Level
Stream or Lake
Normal Water Level
Clear Water Well
Valves
Discharge
Reinf. Concrete Caisson Sealed at Bottom
Aquifer (sand & gravel)
Water Path: a-b-c-d-e
Gate Valves Operated from top
Fines Removed
Screen Pipe 200'-300' long each
Sect.Plan A-A

Radial Collector

Figure 1. INFILTRATION SYSTEMS


33'4"
3'0"
7'7"
10'0"
7'7"
3'0"
PORT
PORT
5'0"
8'0"
ROCK FILL
CONCRETE
36"
CONCRETE
ROCK FILL
36"
5'0"
C.I.
PIPE

TIMBER CRIB

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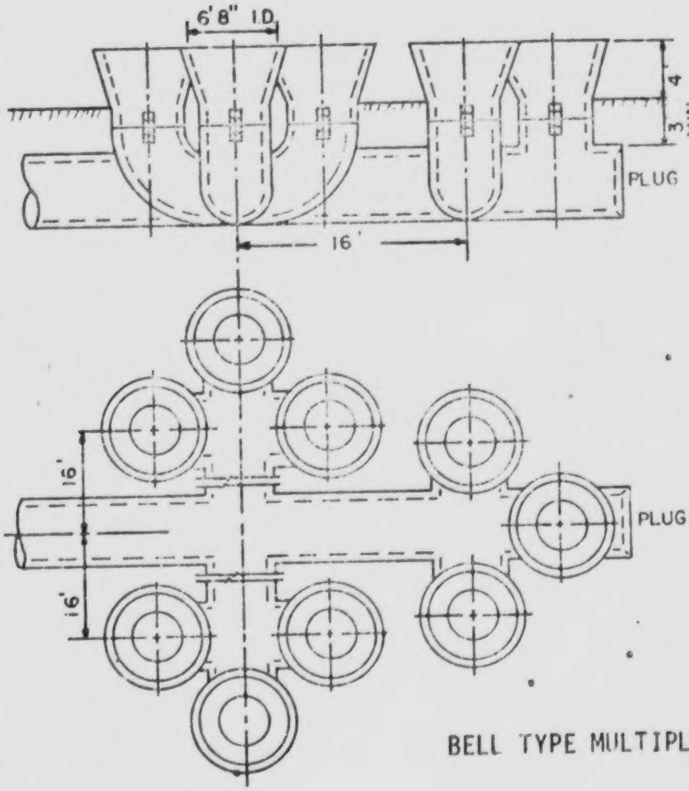
6'8" I.D.
4
3 MIN
PLUG
16'
16'
16'
PLUG

BELL TYPE MULTIPLE CRIB

Figure 2. Examples of typical Lake Michigan municipal water intake structures, Racine, Wisconsin.

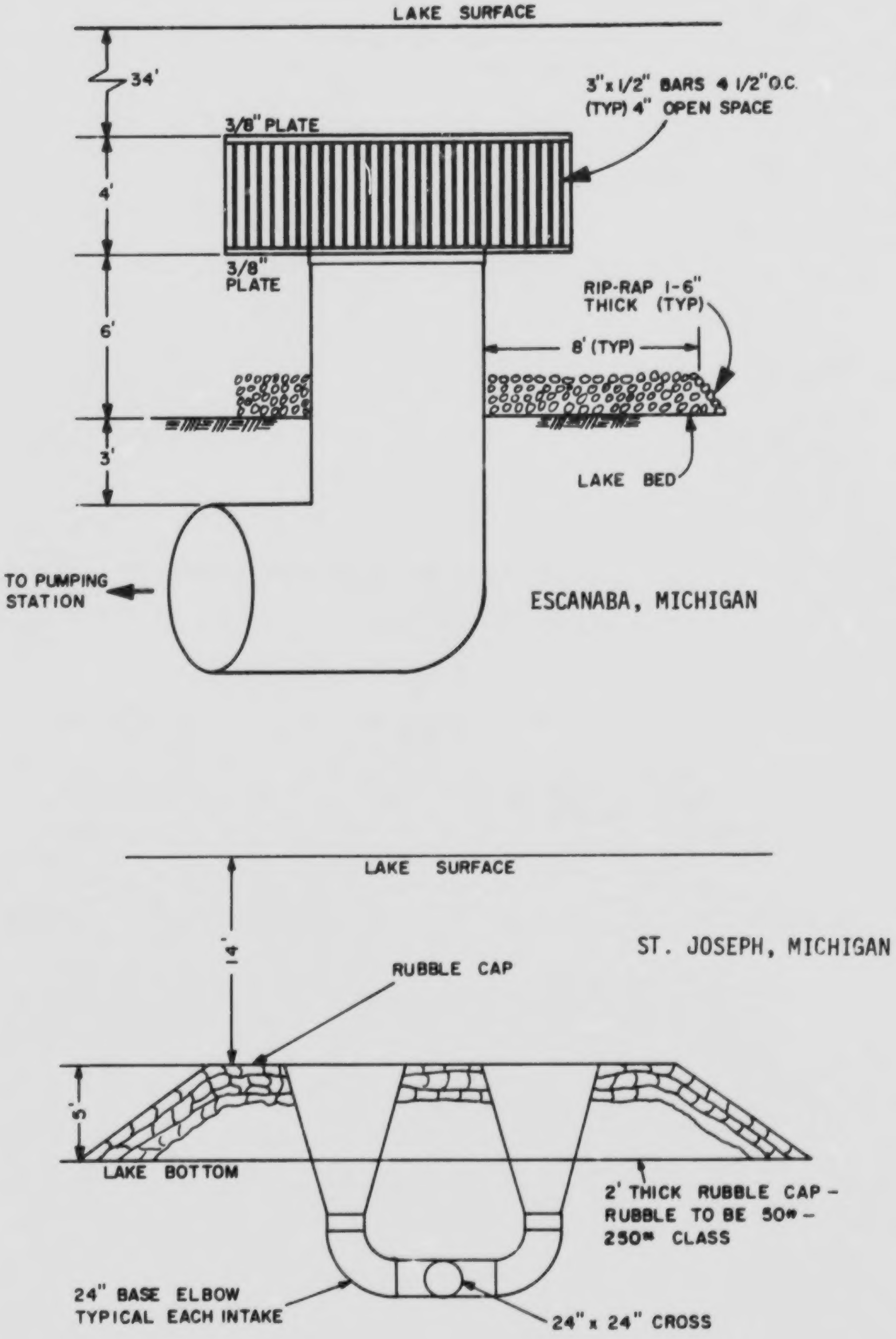
LAKE SURFACE
34'
3"x 1/2" BARS 4 1/2" O.C. (TYP) 4" OPEN SPACE
3/8" PLATE
4'
3/8" PLATE
RIP-RAP 1-6" THICK (TYP)
6'
8' (TYP)
3'
LAKE BED
TO PUMPING STATION
ESCANABA, MICHIGAN
LAKE SURFACE
ST. JOSEPH, MICHIGAN
14'
RUBBLE CAP
5'
LAKE BOTTOM
2' THICK RUBBLE CAP - RUBBLE TO BE 50# - 250# CLASS
24" BASE ELBOW TYPICAL EACH INTAKE
24" x 24" CROSS

Figure 3. Examples of typical Lake Michigan municipal water intake cribs.

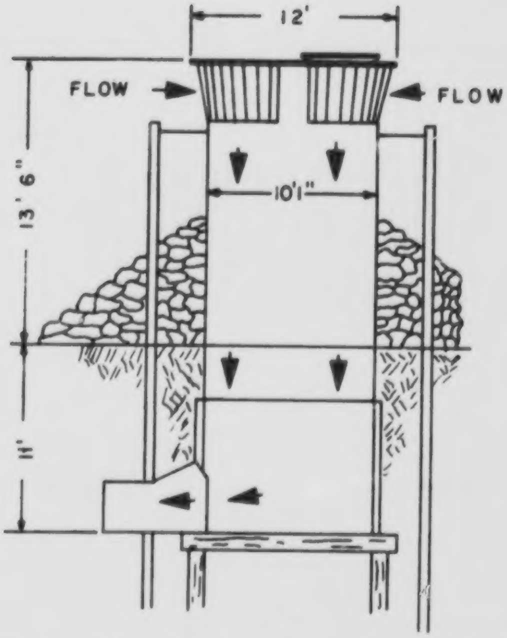
12'
FLOW
FLOW
10'1"
13' 6"
11'

Figure 4. Typical Lake Michigan municipal water intake crib, Benton Harbor, Michigan.

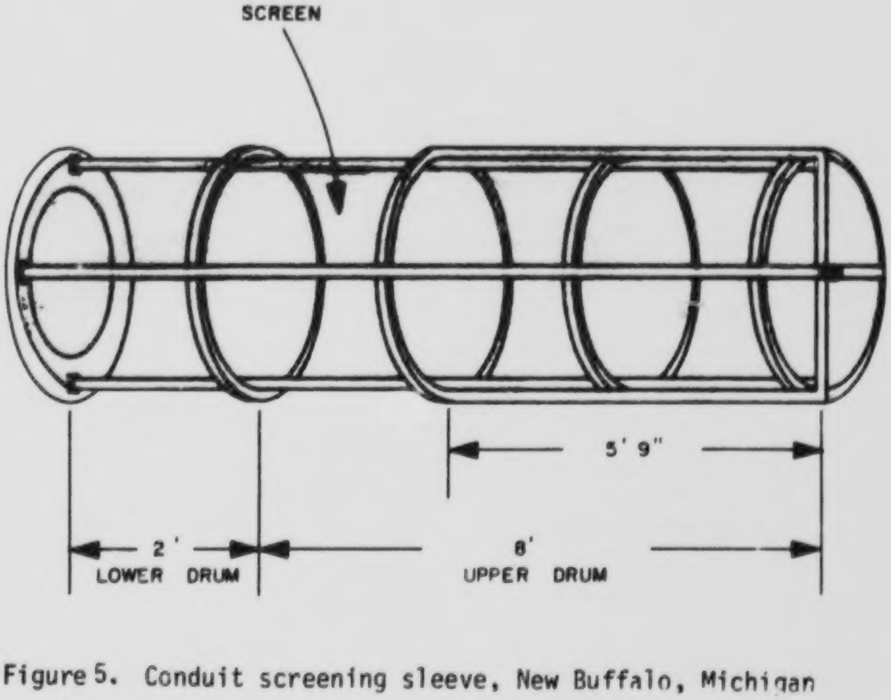
SCREEN
5' 9"
2'
LOWER DRUM
8'
UPPER DRUM

Figure 5. Conduit screening sleeve, New Buffalo, Michigan

facilities backflush to prevent ice formation in the winter months and also to move materials from the screens back out the conduit to the lake. Several facilities also have vertical traveling screens which self-clean at a predetermined frequency. The frequency of cleaning for both manual and automatic screens varied from those facilities which have never cleaned their screens to those which have had to clean every half hour depending on season and lake conditions.

Materials removed from the screens include fish, vegetation (aquatic and terrestrial) and debris. Very few facilities measured the amounts of the various materials removed however, estimates ranged from less than one pound per day to 2,500 pounds per day. The material removed is almost always deposited on land, with only four facilities returning the material to the lake.

None of the municipal intakes indicated that any special devices, barriers or screens had been installed specifically to safely divert fish from entering the intake. The fine mesh screen sleeve, the radial collector and infiltration galleries however, do minimize or prevent the entrainment of fish species. The back-flushing provision of some intakes, depending on frequency of operation, could also be used to minimize fish entrapment by returning fish back to the lake before impingement on the screens can occur.

Industrial Water Intakes

To obtain information regarding current technology as applied to industrial water intakes on Lake Michigan, questionnaires were sent to 19 industries having water intakes in Lake Michigan. Eighteen of the industries queried returned the questionnaire. The information obtained was tabulated by state and industry and is presented in Attachment II.

A brief summary of basic information for industrial intakes is presented in Table 2.

Table 2. Summary data for industries withdrawing water from Lake Michigan.

	No. Industries	Total water withdrawal (cfs)	No. intake structures in lake	No. intakes offshore	Average distance off-shore (feet)
Michigan	5	81	6	3	2,350
Indiana	11	4,884	22	12	2,038
Illinois	3(1)	9	2	2	3,820
Wisconsin	0	-	-	-	-
TOTAL	19	4,974	30	17	-
Average	-	-	-	-	2,736

(1) One did not return questionnaire and is not included in subsequent calculation.

Indiana had the largest number of intakes reporting (11). Five Michigan and three Illinois industries returned the questionnaires. Wisconsin has no industries withdrawing water directly from the lake. In total amount of water withdrawn, Indiana is the largest user with 4,884 cfs followed by Michigan (81 cfs) and Illinois (9cfs). The total amount of water which could be withdrawn by the 18 industries is approximately 5,000 cfs. Of this total approximately

60% (2,938 cfs) is withdrawn by two Indiana steel manufacturing companies (Inland and United States Steel).

The industries are almost evenly divided between those with offshore and onshore intakes, 17 and 13 respectively. For the offshore intakes the point of water withdrawal is on the average about 3,000 feet from the shore. About 50% of the installations with offshore intakes have open cribs (openings larger than 12 inches) with the average size opening for the remainder slightly larger than three inches (3.4 inches) with a range from 1.5 - 4.0 inches. Water velocities reported at the mouth of the offshore intakes ranged from 0.05 - 4.5 fps with the average velocity 1.4 fps. Two offshore intakes reported deicing provisions during the winter months. In both instances warm water was recirculated from the discharge back into the intake forebay.

Of the 13 shoreline intakes reporting,six have no intake trash bars present, with the remaining seven having trash bar spacing ranging from 3.5 - 7.75 inches with the average spacing 5.4 inches. Velocities reported at the mouth of the shoreline intakes averaged 1.76 fps and ranged from 0.01 - 4.2 fps. Approximately seventy percent of the shore intakes utilize some type of deicing procedure during the winter months. Various procedures and techniques were reported, for example, recirculation of warm water, air-bubbler screens and heated trash bars.

No difference between the offshore and onshore industrial intakes were apparent with respect to type, size or operation of screens in the forebay area, therefore they are considered together. The majority of intakes utilize fine mesh screens in the forebay to remove fish, vegetation and debris from the incoming water. Only three facilities - the American Oil Company (Whiting, Ind.), U.S. Steel (Waukegon, Ill.), and Universal Atlas Cement (Gary, Ind.) - had no fine screens installed. Universal Atlas, however, did report installation of a rock barrier and electric fish screens which may eliminate the necessity for the fine mesh screens. There is no uniform size screen opening employed. The sizes of the openings were variable from site to site, ranging from 1/8 - 6 inches, with no size most frequently reported. The type of fine mesh screens installed is almost evenly divided, with 9 stationary, manually cleaned screens and 12 vertical traveling screens which are automatically cleaned. The frequency of cleaning is variable with location on the lake and time of year but generally the screens are cleaned every 8 hours. Materials removed from the screens include fish, vegetation and debris. Most facilities did not report amounts of material removed, however, estimates from several facilities ranged from 1 - 50 pounds of material per day.

Of the eighteen industries which returned the questionnaire, fifty percent have some type of device which would safely prevent fish from entering the intake system. Examples of the various devices include: a cone-shaped fish deflector; nets; air bubble curtains; stone barriers; electric fish screens; and a combination electric screen and air bubbler.

Utility Water Intakes

To obtain information regarding current technology as applied to power plant cooling water intakes on Lake Michigan, questionnaires were sent to 21 facilities with water intakes in the lake. All of the facilities returned the questionnaire. The information obtained was tabulated by state and facility and is presented as Attachment III. A brief summary of basic information for utility cooling water intakes in each state is presented in Table 3.

Table 3. Summary data for power plants withdrawing water from Lake Michigan.

	No. facilities	Total water withdrawal (cfs)	No. intake structures in lake	No. intakes offshore	Average distance offshore (feet)
Michigan	7(1)	5,414	10	8	1,598
Indiana	4	3,158	4	1	1,500
Illinois	2	4,730	2	1	2,600
Wisconsin	8	8,579	12	5	1,686
Total	21	21,881	28	15	--
Average	--	--	--	--	1,846

(1)Does not include Ludington pumped-storage facility.

Wisconsin has the largest number of facilities(8) followed by Michigan (7), Indiana (4) and Illinois (2). Total water withdrawal followed a similar pattern with Wisconsin plants using 8,579 cfs and Michigan 5,414 cfs. Illinois plants although having fewer intakes use more water (4,730 cfs) than Indiana plants (3,158 cfs). This reversal is due to the large nuclear facility located at Zion, Illinois which uses 3,409 cfs of water. The total amount of water which could be withdrawn from Lake Michigan assuming full power plant operation is 21,881 cfs.

Power plant cooling water intakes vary greatly in design and operation around Lake Michigan. It is therefore impossible to typify all aspects of the various intake systems. However, they can easily be classified into offshore and shoreline based on the point of water withdrawal. The Ludington pumped-storage facility at Ludington, Michigan is not included in the following shoreline intake description because of the large volumes of water utilized (66,000 cfs). A general description for this facility is included at the end of this report.

A schematic diagram representing a typical offshore intake in Lake Michigan is presented in Figure 6. The intake distance from shore averages 1846 feet with a range from 350 to 3200 feet. Average water depth over the intake is 20 feet, with the intake openings typically 7 feet above lake bottom. The cribs in place at the end of the intake conduit are variable in design and construction. Two examples of power plant intake cribs are given in Figures 7 and 8. The spacing between adjacent bars employed in the various cribs ranged from 1 inch at the Michigan City Generating Station (Indiana) to 18 inches at the Big Rock Nuclear Plant (Michigan). If the openings were rectangular, the smallest dimension was used in computing the average grillwork opening of about 8 inches. Water velocities at the mouth of the typical crib range from 0.5 - 2.8 fps with an average 1.2 fps. Water velocities at the forebay screens ranged from 0.4 - 2.0 fps and averaged 1.3 fps.

Deicing provisions were indicated in 7 of the 11 plants with offshore intakes. In all cases, deicing is accomplished by recirculation of heated condenser water either to the intake forebay or directly to the intake crib.

Fifty four percent of the power plants with offshore cribs had trash racks in the shoreline forebay area. The average spacing between adjacent bars in the trash racks is 3.4 inches. All facilities with offshore intakes indicated the use of fine mesh

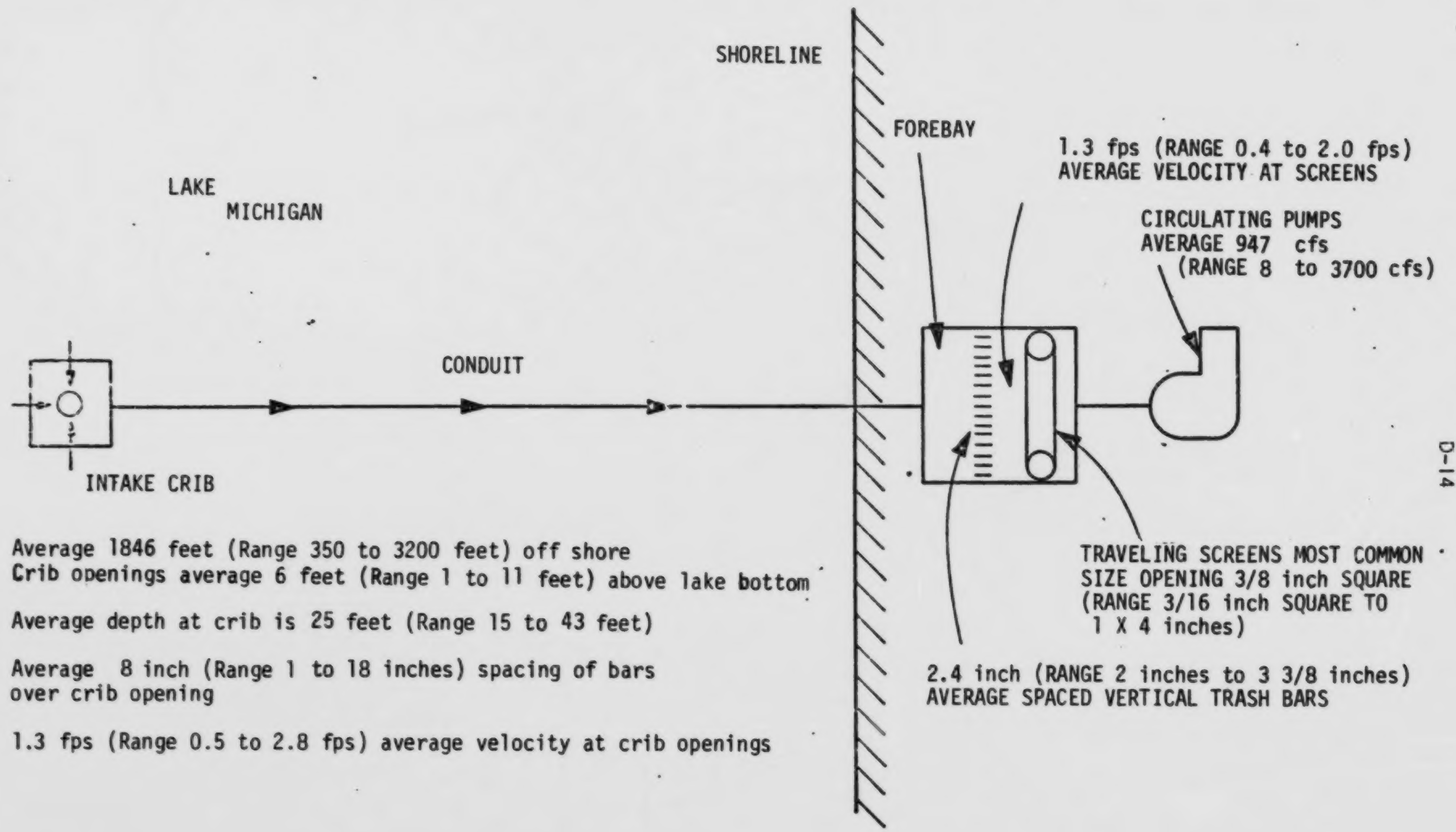
SHORELINE
FOREBAY
1.3 fps (RANGE 0.4 to 2.0 fps)
AVERAGE VELOCITY AT SCREENS
LAKE
MICHIGAN
CIRCULATING PUMPS
AVERAGE 947 cfs
(RANGE 8 to 3700 cfs)
CONDUIT
INTAKE CRIB
Average 1846 feet (Range 350 to 3200 feet) off shore
Crib openings average 6 feet (Range 1 to 11 feet) above lake bottom
Average depth at crib is 25 feet (Range 15 to 43 feet)
Average 8 inch (Range 1 to 18 inches) spacing of bars
over crib opening
1.3 fps (Range 0.5 to 2.8 fps) average velocity at crib openings
TRAVELING SCREENS MOST COMMON
SIZE OPENING 3/8 inch SQUARE
(RANGE 3/16 inch SQUARE TO
1 X 4 inches)
2.4 inch (RANGE 2 inches to 3 3/8 inches)
AVERAGE SPACED VERTICAL TRASH BARS

FIGURE 6

REPRESENTATIVE SCHEMATIC OF A LAKE MICHIGAN POWER PLANT OFFSHORE COOLING WATER INTAKE SYSTEM

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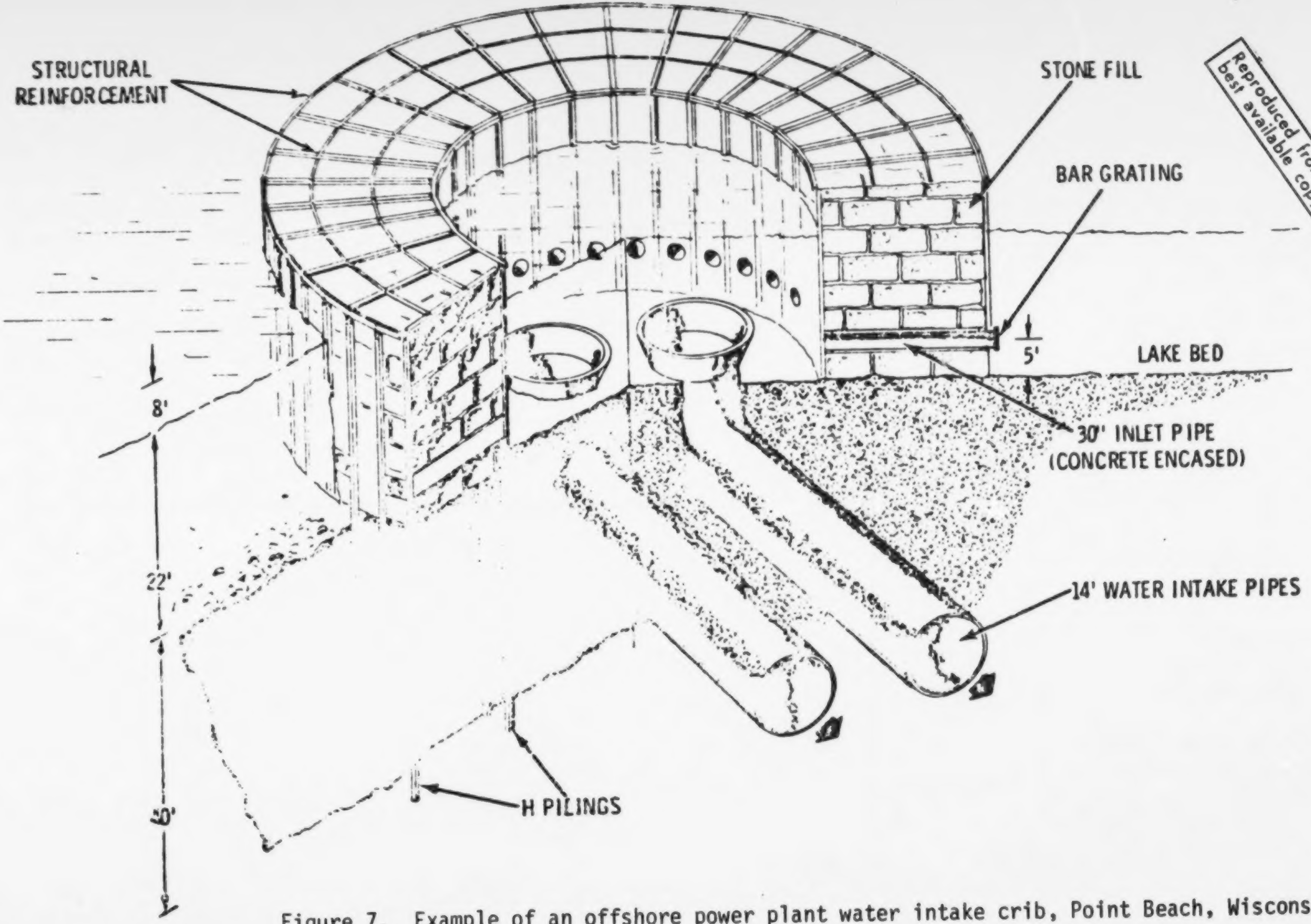
STRUCTURAL REINFORCEMENT
STONE FILL
BAR GRATING
5'
LAKE BED
30' INLET PIPE (CONCRETE ENCASED)
14' WATER INTAKE PIPES
H PILINGS
8'
22'
20'

Figure 7. Example of an offshore power plant water intake crib, Point Beach, Wisconsin

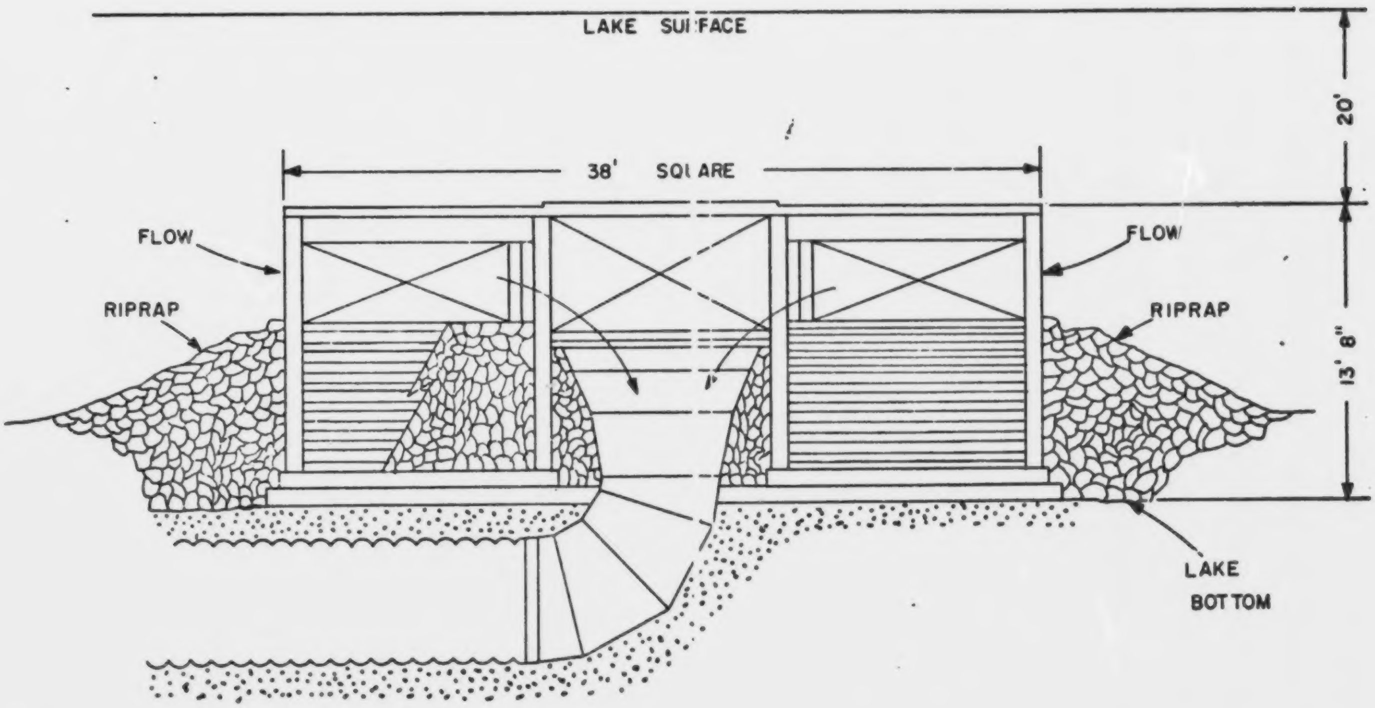
LAKE SURFACE
20'
38' SQUARE
13' 8"
FLOW
FLOW
RIPRAP
RIPRAP
LAKE BOTTOM

Figure 8. Example of an offshore power plant water intake crib, Big Rock Plant, Charlevoix, Michigan.

screens to prevent debris, fish, and vegetation from entering the system. The most frequently encountered (53%) size opening in the screens was 3/8 inch square. Twenty percent of the plants indicated they had 1/2 inch square openings while the remaining 27 percent reported other sizes. Nine plants employed automatically cleaned vertical traveling screens, while three plants had fixed screens which are manually removed and cleaned. The majority of plants with traveling screens reported cleaning them once every eight hours. The Gladstone, Michigan Generating Station however, only clean their screens twice a year, in the spring and fall.

A representative schematic of a Lake Michigan power plant shoreline cooling water intake is presented in Figure 9. The intake mouth may be located either onshore (with or without protective seawalls extending into the lake) or on a channel extending from the shore to the plant location. The water velocities at the mouth of the intake range from 0.5 - 4.5 fps with the average 2.0 fps. All of the plants with shoreline intakes have provisions for winter deicing. In all instances a portion of the warm discharge water is recirculated to the intake mouth or forebay area. All plants employing shoreline intakes had trash racks. The average spacing between adjacent bars is 2.8 inches with a range of 1 to 4 inches. Each plant also uses fine mesh screens in the intake forebay. Fifty percent of the plants had screens with 3/8 inch square openings, 20 percent with 5/16 inch square openings, with 30 percent reporting other sizes. Almost all facilities had vertical traveling screens which are self-cleaning. The cleaning procedure is either activated manually, by a timer or by head loss across the screens. One facility (Escanaba, Michigan) employs fixed screens which are manually cleaned only when needed. The majority of plants however, clean their screens once every 8 hours.

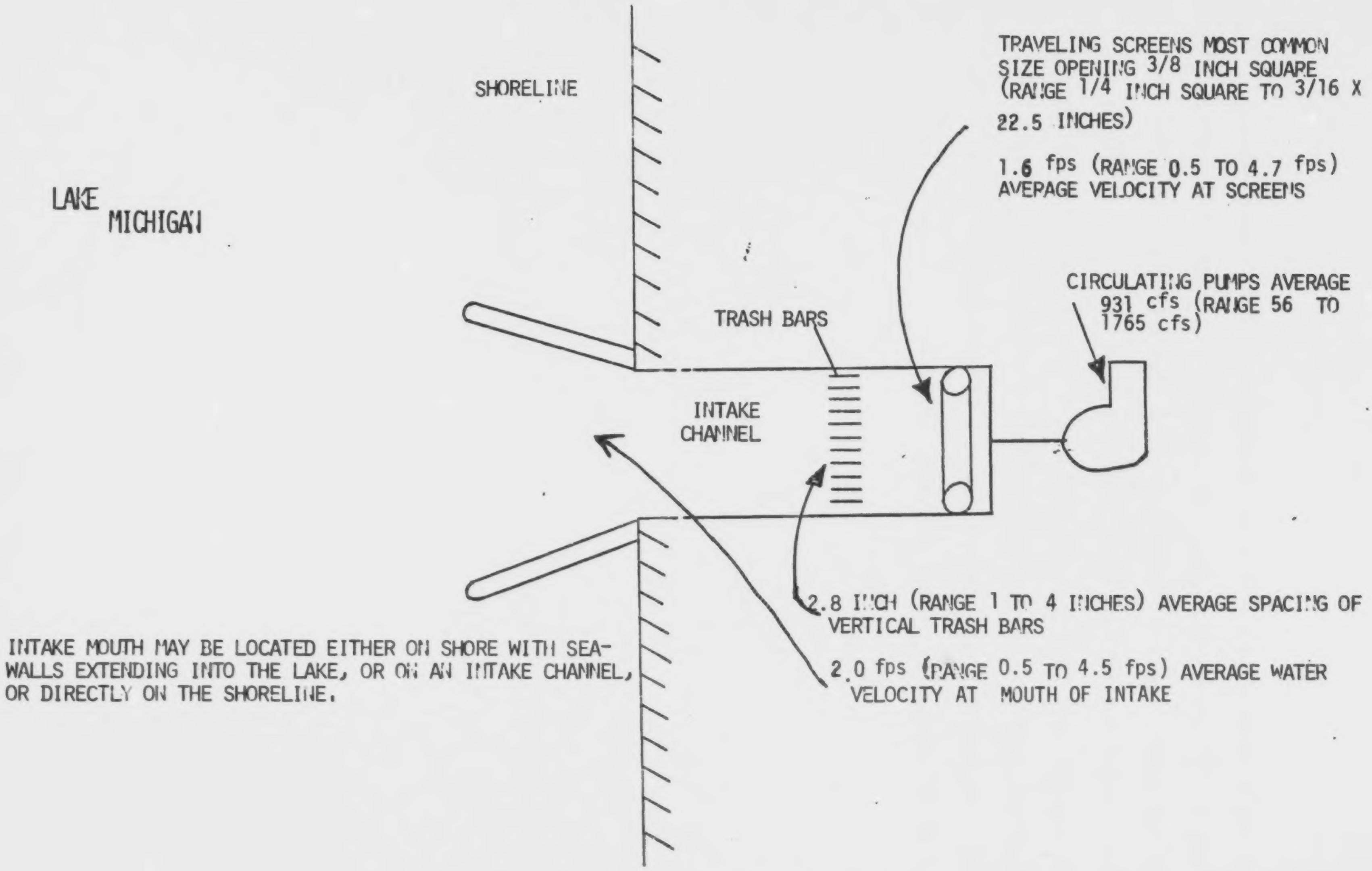
LAKE MICHIGAN
SHORELINE
TRASH BARS
INTAKE CHANNEL
TRAVELING SCREENS MOST COMMON SIZE OPENING 3/8 INCH SQUARE (RANGE 1/4 INCH SQUARE TO 3/16 X 22.5 INCHES)
1.6 fps (RANGE 0.5 TO 4.7 fps) AVERAGE VELOCITY AT SCREENS
CIRCULATING PUMPS AVERAGE 931 cfs (RANGE 56 TO 1765 cfs)
2.8 INCH (RANGE 1 TO 4 INCHES) AVERAGE SPACING OF VERTICAL TRASH BARS
2.0 fps (RANGE 0.5 TO 4.5 fps) AVERAGE WATER VELOCITY AT MOUTH OF INTAKE
INTAKE MOUTH MAY BE LOCATED EITHER ON SHORE WITH SEAWALLS EXTENDING INTO THE LAKE, OR ON AN INTAKE CHANNEL, OR DIRECTLY ON THE SHORELINE.

FIGURE 9

REPRESENTATIVE SCHEMATIC OF A LAKE MICHIGAN POWER PLANT SHORELINE COOLING WATER INTAKE SYSTEM

Of the 21 power plants with water intakes in Lake Michigan 7 employ some type of fish screening device. The plants with offshore crib intakes include one plant employing a rock filled crib (Traverse City, Michigan) and one plant with an air bubble screen (Kewaunee, Wisconsin). The shoreline intakes reported air bubble screens (Campbell Plant, Pt. Sheldon, Michigan; Pulliam Plant, Green Bay, Wisconsin), electric screens (Mitchell Plant, Gary, Indiana), combination air bubble and electric screens (Michigan City, Indiana) and a fish net across the intake (Waukegan, Illinois).

Ludington Pumped-Storage Facility

The Ludington Pumped-Storage power plant is a new hydro-electric facility located at Ludington, Michigan. The plant when completely operational will produce 1872 megawatts of power and will withdraw and return, after storage in an upper reservoir, approximately 66,000 cfs of water from Lake Michigan. This volume of water is significant in that it is more than twice the volume withdrawn by all other municipal, industrial and utility intakes combined. This large volume of water is pumped into an 830 acre upper storage reservoir using power drawn from conventional power plants during low demand periods, usually at night and on weekends. The Water is released during the day at peak demand periods and the pumps that moved the water to the storage reservoir then become generators. Depending on the demand anywhere from 1 to 6 pump-turbines can be operated.

The water velocity at the mouth of the intake in the pumping mode is 1.5 fps, while the average velocity at the trash racks is 8.75 fps. There are no fine mesh screens in the system.

A separate water intake is also installed to provide water for motor bearing and oil cooling. The system will operate on a temperature demand principle with 7 pumps, each with a capacity of 14.5 cfs, activated as needed to provide a maximum of 101.5 cfs of cooling water. There are 3 manually removable screens with 1" x 4" openings for this cooling water system.

The facility has had no experience yet in cleaning procedures or types of material removed from the cooling water intake. An environmental assessment program is being carried out by Michigan State University to determine the impact of the total facility on populations of aquatic organisms in Lake Michigan.

ATTACHMENT I

Lake Michigan Water Intake Information for Municipalities

LAKE MICHIGAN WATER INTAKE INFORMATION FOR MICHIGAN MUNICIPALITIES (PART I)

City	Type of* structure	Distance off shore (in feet)	Water depth over intake opening (in feet)	Distance of opening above lake bottom (in feet)	Spacing of intake bars (in inches)	Deicing provisions	Velocity at mouth of intake (fps)	Velocity at screens (fps)	Flow rate at pumps (cfs)
Benton Harbor	Crib	3885	17	10	8.0	Yes	5.3	-------	37.1
Bridgman	Radial collector	100	below lake bottom	NA	NA[1]	No	NA	NA[2]	0.9
Escanaba	Crib	1200	50	--	--	--	--	-------	-----
Gladstone	Crib	1500	31	9	--	No	--	2.0	6.0
Grand Beach	DID NOT RETURN QUESTIONNAIRE								
Grand Haven	Radial collector (3)	shore-line	below lake bottom	NA	NA[1]	Yes	NA	NA[2]	8.0
	Infil-tration gallery	500	below lake bottom	NA	NA[1]	Yes	NA	NA[2]	5.0
Grand Rapids	Crib	6000	47	10	2.0	No	--	7.0	93.0
Holland	Crib	4475	35	4	12.0	No	--	--------	25.5
Ludington	Crib	2800	20	5	1.0	Yes	--	---------	3.1 total
	Infil-tration gallery	900	below lake bottom	NA	NA[1]	Yes	NA	NA[2]	
Menominee	Crib	1850	14	7	0.5[4]	Yes	3.1	NA[3]	6.2 total
	Pipe	850	15	5	0.5[5]	Yes	--	NA[3]	
Michiana	Infil-tration line (3)	30	below lake bottom	NA	NA[1]	No	NA	NA[2]	1.1
Muskegon	Crib	6000	31	6	12.0	No	0.1	1.7	34.0
Muskegon Heights	Crib	4600	45	5	15.0	Yes	0.2	0.7	29.5
New Buffalo	Crib	4500	26	7	10.5	No	--	----	3.1
St. Joseph	Crib	1490	14	5	2.3	Yes	0.2	1.3	20.0
South Haven	Crib	5650	32	8	9.0	No	0.2	0.7	12.5
Traverse City	Crib	4120	32	7	12.0	No	0.2	----	31.0
Wyoming	Crib (2)	4500	34	8	12.0	No	0.2	2.3	99.0

NA = Not Applicable
-------- indicates data not supplied on questionnaire
* = number in parenthesis denotes number of structures
[1] Water is filtered through aquifer
[2] No screens needed
[3] No screens present
[4] 0.5 inch holes are drilled on 2 inch centers
[5] Pipe is covered with a perforated sleeve having 0.5 inch holes drilled on 2 inch centers

LAKE MICHIGAN WATER INTAKE INFORMATION FOR MICHIGAN MUNICIPALITIES (PART II)

City	Number of screens	Size of openings (in inches)	How screens are cleaned[1]	Frequency of cleaning	Type of material removed	Estimated weight of material removed	Deposition of material	Variations
Benton Harbor	1	3/8 sq.	A	every 8 hours	debris, fish	0-30 lbs.	land	increase in material during the fall and during storms
Bridgman	0[2]							
Escanaba	0							
Gladstone	2	1/4 sq.	M	once/year	debris	---------	------	none
Grand Beach	DID NOT RETURN QUESTIONNAIRE							
Grand Haven	0[2]							
Grand Rapids	1	3/8 sq.	M	not used since 1963				
Holland	2	3/4 sq.	M	once/month	vegetation, fish	---------	------	increase in vegetation during fall months
Ludington	0							
Menominee	0[3]	1/2 sq.	NA	----------	NA	NA	Lake	backflushed when necessary
Michiana	0[2]							
Muskegon	2	7/16 sq.	M	summer: 3 times/ week winter: once/ week	fish, debris	2-15 pounds per cleaning	land	more alewives in summer
Muskegon Heights	2	1/2 sq.	M	twice/year	vegetation	100 lbs. annually	land	none
New Buffalo	1[4]	3/8 X 4 3/16	M	once/year	none	none	none	none
St. Joseph	1	3/8 sq.	A	from 1/2 to 4 hours	vegetation, debris	----------	land, sometimes returned to lake	increased material during spring and fall
South Haven	2	3/4 sq.	M	twice/year (spring and fall)	debris	----------	land	increased material during spring and fall
Traverse City	2	1/4 sq.	A	never	none	none	none	none
Wyoming	2	1/2 sq.	M	once/week	fish, vegetation	-----------	--------	more algae with warmer water

--------- indicates data not supplied on questionnaire

[1] A = Automatically cleaned traveling screens actuated by timer, pressure differential or manually
M = Manual removal and cleaning of screens

[2] Radial collectors and infiltration galleries utilize the natural filtration properties of sand and gravel so no screens are needed

[3] Cover over crib opening has 1/2 inch diameter holes drilled on 2 inch centers

[4] New Buffalo has a cylindrical screen, closed on the top end, which slides into the crib and over the end of the intake opening, creating an end line type filter.

LAKE MICHIGAN WATER INTAKE INFORMATION FOR INDIANA MUNICIPALITIES (PART I)

City	Type of* Structure	Distance off shore (in feet)	Water depth over intake opening (in feet)	Distance of opening above lake bottom (in feet)	Spacing of intake bars (in inches)	Deicing provisions	Velocity at mouth of intake (fps)	Velocity at screens (fps)	Flow rate at pumps (cfs)
East Chicago	Crib (4)	9240	NA	NA	NA	No	NA	NA	-----
Gary-Hobart Water Corporation Gary Plant	Crib	5500	33	11	3/8	No	0.2	0.1	83.5
Ogden Dunes Plant	Crib (3)	1950	13	12	1 3/16 X 4	No	0.3	0.1	37.1
Hammond									
42" line	Crib	4500	18	6	stone filled crib	No	-----	-----	-----
60" line	Crib (3)	2500	17	5	18	No	0.2	-----	------

NA = Not applicable
----- indicates data not supplied on questionnaire
* number in parenthesis denotes number of structures

LAKE MICHIGAN WATER INTAKE INFORMATION FOR INDIANA MUNICIPALITIES (PART II)

City	Number of screens	Size of openings (in inches)	How screens[1] are cleaned	Frequency of cleaning	Type of material removed	Estimated weight of material removed	Deposition of material	Variations
East Chicago	2	3/4 X 2 1/2	M	3 times/year	Debris, vegetation	--------	Land	None
Gary-Hobart Water Corporation								
Gary Plant	1	17/64 sq.	M	once/month	Debris, fish	less than 1 lb./day	Land	Screens cleaned more frequently in spring and fall
Ogden Dunes Plant	1	1 X 3 3/16	M	3 times/year	Debris, fish	---------	Land	Increased amounts of material in spring and fall
Hammond								
42" line	1[2]	3/8 sq.	A	once/day	Debris, vegetation	2 lbs./day	Land	None
60" line								

------- indicates data not supplied on questionnaire

[1] A= Automatically cleaned traveling screens actuated by timer, pressure differential or manually

M= Manual removal and cleaning of screens

[2] 42" and 60" lines are served by a common filtration plant

LAKE MICHIGAN WATER INTAKE INFORMATION FOR ILLINOIS MUNICIPALITIES (PART I)

City	Type of structure*	Distance off shore (in feet)	Water depth over intake opening (in feet)	Distance of opening above lake bottom (in feet)	Spacing of intake bars (in inches)	Deicing provisions	Velocity at mouth of intake (fps)	Velocity at screens (fps)	Flow rate at pumps (cfs)
CHICAGO									
South plant	Crib	12144	22	-----	----	Yes	1.2	0.2[1]	613[1]
	Shoreline	NA	NA	NA	NA	Yes	3.2		
Central plant	Crib	15000	35	-----	open	Yes	1.5	0.6[1]	1,048[1]
	Shoreline	NA	NA	NA	NA	Yes	1.0		
EVANSTON									
36" line	Crib	5600	24	9	open	No	0.2	------	12[1]
48" line	Crib	1800	12	-----	open	No	0.8	------	
GLENCOE	DID NOT RETURN QUESTIONNAIRE								
HIGHLAND PARK									
16" line	Crib	2000	20	11	3/8	No	6.0	NA[2]	12[1]
20" line	Crib	3500	18	-----	7/16	No	3.6	NA[2]	
30" line	Crib	1000	9	-----	6	No	2.0	NA[2]	
HIGHWOOD	Crib	2600	24	5	1	No	---	---	1
KENILWORTH	Pipe[3]	2100	24	6	3/8	No	---	---	2
LAKE FOREST	Crib	2975	25	5	2	----	0.6	---	50
NORTH CHICAGO	DID NOT RETURN QUESTIONNAIRE								
WAUKEGAN	Crib (3)	6244	28	-----	6	No	0.1	2.5	15
WILMETTE	DID NOT RETURN QUESTIONNAIRE								
WINNETKA									
60" line	Crib	1200	20	-----	1	No	3.3	-----	63[1]
20" line	Crib[4]	3000	20	5	1 1/2	No	3.3	-----	

NA = Not Applicable
---- indicates data not supplied on questionnaire
* number in parenthesis denotes number of structures
1 Intake waters are combined before reaching screens
2 No screens employed
3 Pipe is fitted with a 12' long X 2' dia. straining device having 3/8" dia. perforations
4 28' X 20' cylindrical strainer over cast iron pipe

LAKE MICHIGAN WATER INTAKE INFORMATION FOR ILLINOIS MUNICIPALITIES (PART II)

City	Number of screens	Size of openings (in inches)	How screens[1] are cleaned	Frequency of cleaning	Type of material removed	Estimated weight of material removed	Deposition of material	Variations
CHICAGO South plant	33	1 sq.	M	2 to 5 times/week	Debris, fish vegetation	0 to 2,500 lbs./day	land	Screens are removed during winter months
Central plant	8	1/2 sq.	A	once/8 hours	Debris, fish vegetation	---------	fish & vegetation returned to lake - debris to land	future plans call for re-routing screen material from lake to sewer system
EVANSTON	----	3/8 sq.	A	once/24 hours	Debris, fish vegetation	---------	----------	None
		3/4 x 3 3/4	M	once/24 hours				
GLENCOE	DID NOT RETURN QUESTIONNAIRE							
HIGHLAND PARK	0							
HIGHWOOD	1	1/4 sq.	M	once/month	vegetation	3 lbs./month	land	Screens are cleaned only during May thru Oct.
KENILWORTH	0[2]							
LAKE FOREST	2[3]	3/4 sq.	M					
NORTH CHICAGO	DID NOT RETURN QUESTIONNAIRE							
WAUKEGAN	1	3/8 sq.	A	once/8 hours	vegetation	5 lbs./day	sewer	None
WILMETTE	DID NOT RETURN QUESTIONNAIRE							
WINNETKA	1	3/8 sq.	A	once/week	fish, vegetation	20 lbs./week	land	Winnetka Electric Utility draws water from same intake

----- indicates data not supplied on questionnaire

[1] A = Automatically cleaned traveling screens activated by timer, pressure differential or manually
M = Manual removal and cleaning of screens

[2] A straining device over the mouth of the intake pipe has 3/8 in. dia. perforations

[3] Presently under construction

LAKE MICHIGAN WATER INTAKE INFORMATION FOR WISCONSIN MUNICIPALITIES (PART I)

City	Type of* structure	Distance off shore (in feet)	Water depth over intake opening (in feet)	Distance of opening above lake bottom (in feet)	Spacing of intake bars (in inches)	Deicing provisions	Velocity at mouth of intake (fps)	Velocity at screens (fps)	Flow rate at pumps (cfs)
Cudahy	Crib (new)	5900	37	8	open	Yes	0.01	0.2	38.6
	Crib (old)	2800	24	8	1.6	Yes	0.2	-------	13.3
Glendale	Crib (3)	4100	33	7	6.0	Yes	0.2	0.4	34.0
Green Bay	Crib (9)	3000	50	4	open	No	0.1	2.4	70.0 total
	Crib (3)	6000	50	4	open	No	0.1	2.4	
Kenosha	open pipe	200	23	6	open	No	0.6	------	6.0 total
	Crib	4700	35	--	3.0	No	0.6	-------	
Manitowoc	Crib (3)	9000	34	5	5.5	No	0.1	--------	15.5
	Radial collector	shore-line	below lake bottom	NA	NA[1]	No	NA	NA[2]	9.0
Marinette	Crib (2)	2200	23	9	3.0	No	--	-------	10.0
Milwaukee									
Howard Ave. Crib		7500	50	10	8.0	No	0.1	0.1	54.0
Linwood Ave. Crib		6565	67	12	2.0	No	0.1	0.1	154.7
Port Washington	Crib (new)	2100	31	6	3.0	Yes	0.5	NA[3]	9.2 total
	Crib (old)	3450	40	--	3.0	Yes	---	NA[3]	
Racine									
New	Crib (9)	4100	24	4	12.0	No	0.4	NA[3]	69.6 total
1923 line	Crib	6400	40	4	open	No	0.2	NA[3]	
1886 line	Crib	6300	40	7	2.0	No	0.2	NA[3]	
Sheboygan									
30" line	Crib	5000	45	13	2.0	Yes	0.1	NA[3]	76.0 total
20" line	Crib	1850	24	3	open	Yes	1.3	NA[3]	
36" line	Crib (9)	1200	10	5	2.0	Yes	0.1	NA[3]	
South Milwaukee	Crib	3000	31	0	2.0	Yes	--------	--------	14.0
Two Rivers	Crib	6126	33	7	2.0	No	--	------	--------

NA = Not applicable
------ indicates data not supplied on questionnaire
* = number in parenthesis denotes number of structures
[1] Water is filtered through aquifer
[2] No screens needed
[3] No screens present

LAKE MICHIGAN WATER INTAKE INFORMATION FOR WISCONSIN MUNICIPALITIES (PART II)

City	Number of screens	Size of openings (in inches)	How screens[1] are cleaned	Frequency of cleaning	Type of material removed	Estimated weight of material removed	Deposition of material	Variations
Cudahy (new)	2	1 X 4	M	not known	vegetation	------	land	none
Cudahy (old)	9	1/2 dia.	M	as required	vegetation	100 to 500 pounds/day at times	land	none
Glendale	1	3/8 sq.	A	twice/month	vegetation, fish	---------	returned to lake	increased number of fish during late spring, more plants and algae in late summer
Green Bay	2	1 sq.	M	once/year (fall)	fish	10 pounds	returned to lake	fish are a problem in fall
Kenosha								
East plant	2	1 sq.	M	fall and summer: once/month winter: once/3 months	fish	5 lbs./month	land	cleaned more often during summer, spring, and fall
West plant	1	1 1/4 sq.	M					
Manitowoc[2]	1	3/8 sq.	A					
Marinette	1	1/2 sq.	A	twice/week	vegetation	-----------	land	increased amounts of material during spring and fall
Milwaukee								
Howard Ave.	4	1 sq.	M	once/year (spring)	vegetation, debris, fish	less than 1 cubic yard/year	land	none
Linwood Ave.	0							
Port Washington	0							
Racine	0							
Sheboygan	0							
South Milwaukee	1	2 sq.	M	3 times/year	vegetation	----------	land	-------------
Two Rivers	1	1/4 sq.	M	once/year	vegetation, debris	95 pounds/day[3]	land	none

------ indicates data not supplied on questionnaire

[1] A - Automatically cleaned traveling screens actuated by timer, pressure differential or manually
M - Manual removal and cleaning of screens

[2] Manitowoc presently uses a radial collector. The travelling screen system is for a newly installed crib intake and no cleaning information is yet available.

[3] Material is trapped in a shorewell which is cleaned annually. 95 pounds/day is an estimate.

ATTACHMENT II

Lake Michigan Water Intake Information for Industries

LAKE MICHIGAN WATER INTAKE INFORMATION FOR MICHIGAN INDUSTRIES (PART I)

Plant name and location	Type of* structure	Distance off shore (in feet)	Water depth at intake location (in feet)	Distance of opening above lake bottom (in feet)	Spacing of crib intake bars (in inches)	Intake deicing provisions	Velocity at mouth of intake (fps)	Velocity at screens (fps)	Flow rate at pumps (cfs)
American Playground and Device Company Nahma	Crib (2)	1320	------	6.0	-----	No	------	------	1
Escanaba Paper Company (Mead Corporation) Escanaba	Crib	3380	42.0	8.0	4.0**	No	2.2	1.0	62
Inland Lime and Stone Company Gulliver	Shoreline	NA	NA	NA	NA	No	5.0	5.0	11
Medusa Portland Cement Company Charlevoix	Shoreline	NA	NA	NA	NA	No	0.3	0.2	4
Penn-Dixie Cement Corporation Petoskey	Shoreline	NA	NA	NA	NA	Yes	-------	------	3

NA = Not Applicable
----- indicates data not supplied on questionnaire
* Number in parenthesis denotes number of structures
** Also covered with 1.5" sq. wire mesh screen

LAKE MICHIGAN WATER INTAKE INFORMATION FOR MICHIGAN INDUSTRIES (PART II)

Plant name and location	Trash bar spacing (in inches)	Number of screens	Intake screen openings (in inches)	Method of cleaning screens*	Frequency of cleaning	Type and estimated weight of material removed	Intake fish screening devices present
American Playground** and Device Company Nahma	NA	2	6 sq.	M	once/2 years	rust and scale	------------
Escanaba Paper Company Mead Corporation Escanaba	NA	1	3/8 sq.	A	-------	debris, fish vegetation 1 lb./day	cone shaped deflector above intake crib
Inland Lime and Stone Company Gulliver	NA***	1	1/8 sq.	M	as needed	fish, vegetation 5 lbs./cleaning	air bubble screen
Medusa Portland Cement Company Charlevoix	NA***	2	1/2 sq.	M	not necessary	none	none
Penn-Dixie Cement Company Petoskey	NA***	1	3/8 sq.	A	---------	fish	none

NA = Not applicable
------ indicates data not supplied on questionnaire
* A = Automatically cleaned traveling screens actuated by timer, pressure differential or manually
M = Manual removal and cleaning of screens
** Plant expects to convert to 1290 feet deep well in July 1973
*** None present

LAKE MICHIGAN WATER INTAKE INFORMATION FOR INDIANA INDUSTRIES (PART I)

Plant Name and Location	Type of Structure*	Distance off shore (in feet)	Water depth at intake location (in feet)	Distance of opening above lake bottom (in feet)	Spacing** of crib intake bars (in inches)	Intake deicing provisions	Velocity at mouth of intake (fps)	Velocity at screens (fps)	Flow rate at pumps (cfs)
American Maize-Products Company, Roby	crib	2300	------	3	open	No	-------	0.7	19
American Oil Company, Whiting Refinery, Whiting	Crib (2)	1400	20	4	open	No	0.5	NA	250 total
		1100	20	4	open	No	0.5	NA	
Bethlehem Steel Corporation, Burns Harbor Plant, Chesterton	crib (2)	3500	-------	4	4	No	0.3	1.4	685
Inland Steel Company, East Chicago	shoreline (2)	NA	NA	NA	NA	Yes	East 0.8 North 0.4	East 0.7 North 0.6	East 1448 North 223
Lever Brothers Company, Hammond	crib	2000	------	6	open	No	4.1	0.8	29
Midwest Steel, Portage	crib	2800	34	6	3.5	Yes	0.05	0.04	11
Union Carbide Corporation, Whiting	crib (2)	1730	-----	6	open	No	1.8	1.0	89
Union Carbide Linde Division, Gary	crib	550	-----	9	open	Yes	1.0	3.5	154
Universal Atlas Cement, Gary									
Buffington pump station	shoreline	NA	NA	NA	NA	Yes	0.01	NA	2
Power station pump station	shoreline	NA	NA	NA	NA	Yes	0.01	NA	3
U.S. Steel Corporation Gary Works, Gary									
Lakeside pump station	crib	3000	40	7	3.5	No	0.2	0.5	215
Central pump station	crib	2000	-----	8	------	No	1.3	1.8	38
No. 1 pump station	shoreline	NA	NA	NA	NA	Yes	4.2	1.4	476
No. 2 pump station	shoreline	NA	NA	NA	NA	Yes	1.2	1.9	414
No. 4 pump station	shoreline	NA	NA	NA	NA	No	0.8	1.2	124
Yougstown Sheet and Tube Company, East Chicago									
No. 1 intake	shoreline	NA	NA	NA	NA	No	0.1	0.1	56
No. 2 intake	shoreline	NA	NA	NA	NA	------	1.1	0.3	424
No. 3 intake	shoreline	NA	NA	NA	NA	------	0.1	0.1	224

NA = Not Applicable
----- indicates data not supplied on questionnaire
* Number in parenthesis denotes number of structures
** crib ports greater than 12" were considered open

LAKE MICHIGAN WATER INTAKE INFORMATION FOR INDIANA INDUSTRIES (PART II)

Plant Name and Location	Trash bar spacing (in inches)	Number of screens	Intake screen openings (in inches)	Method of cleaning screens*	Frequency of cleaning	Type and estimated weight of material removed	Intake fish screening devices present
American Maize-Products Company, Roby	NA	1	3/4 dia.	M	last cleaned in 1963	NA	None
American Oil Company, Whiting Refinery, Whiting	NA	0	NA	NA	NA	NA	None
Bethlehem Steel Corporation, Burns Harbor Plant, Chesterton	1	6	1/4 sq.	A	as required	Debris, no estimate	None
Inland Steel Company, East Chicago	3.5	31	5/32 sq.	A	as required	Debris, fish, vegetation no estimate	A net is stretched across the east intake during alewife runs to block fish both intakes have air bubblers
Lever Brothers Company, Hammond	NA	1	1/4 X 1	M	once/ 8 hours	Debris, fish vegetation 50 pounds/day	None
Midwest Steel, Portage	NA	2	1/4 sq.	A	once/8 hours	fish**	None
Union Carbide Corporation, Whiting	NA	2	half 1/4 sq. half 1 sq.	A	continuous	Debris, fish 25 to 50 pounds/day	None
Union Carbide Linde Division, Gary	2	3	1/8 sq.	A	once/45 min.	Debris, fish vegetation 10 pounds/day	None
Universal Atlas Cement, Gary							
Buffington pump station	3 3/8	0	NA	NA	NA	NA	stone barrier and electrical fish screen
Power station pump station	NA	0	NA	NA	NA	NA	stone barrier
U.S. Steel Corporation Gary works, Gary							
Lakeside pump station	NA	4	3/16 sq.	A	once/8 hours	Debris, fish no estimate	None
Central Pump station	NA	2	1/8 sq.	A	once/8 hours	Debris, fish no estimate	None
No. 1 pump station	7 3/4	14	1/8 sq.	A	once/8 hours	fish, vegetation, no estimate	None
No. 2 pump station	7 1/4	6	1/8 sq.	A	once/8 hours	fish, vegetation, no estimate	None
No. 4 pump station	NA	4	1/8 sq.	A	once/8 hours	fish, vegetation, no estimate	None
Youngstown Sheet and Tube Company East Chicago							
No. 1 Intake	6	6	4 sq.	M	once/ 8 hours	Debris, no estimate	Submerged air bubbler
No. 2 Intake	4	5	4 sq.	M	once/8 hours	Debris, no estimate	Electric fish screen and submerged air bubbler
No. 3 Intake	6	6	4 sq.	M	once/8 hours	Debris, no estimate	Electric fish screen and submerged air bubbler

NA = Not applicable

-------- indicates data not supplied on questionnaire

* A = Automatically cleaned traveling screens activated by timer, pressure differential or manually

M = Manual removal and cleaning of screens

** Three small fish in twelve years of operation

LAKE MICHIGAN WATER INTAKE INFORMATION FOR ILLINOIS INDUSTRIES (PART I)

Plant name and location	Type of structure	Distance off shore (in feet)	Water depth at intake location (in feet)	Distance of opening above lake bottom (in feet)	Spacing of crib intake bars (in inches)	Intake deicing provisions	Velocity at mouth of intake (fps)	Velocity at screens (fps)	Flow rate at pumps (cfs)
Johns-Manville Products Corporation Waukegan	Crib	840	23	open		No	0.3	0.3	4
U. S. Steel Waukegan Works	Crib	6800	35	10	4 X 4	No	1.6	----	5
U. S. Steel South Works	DID NOT RETURN QUESTIONNAIRE								

LAKE MICHIGAN WATER INTAKE INFORMATION FOR ILLINOIS INDUSTRIES (PART II)

Plant name and location	Trash bar spacing (in inches)	Number of screens	Intake screen openings (in inches)	Method of cleaning screens	Frequency of cleaning	Type and estimated weight of material removed	Intake fish screening devices present
Johns-Manville Products Corporation Waukegan	NA	3	1 sq.	M	once/week (summer) once/3 weeks (winter)	fish, vegetation, 1 lb./day	floating log barrier
U.S. Steel Waukegan Works	NA	0	NA	NA	NA	NA	NA
U.S. Steel South Works	DID NOT RETURN QUESTIONNAIRE						

ATTACHMENT III

Lake Michigan Water Intake Information for Utilities

LAKE MICHIGAN WATER INTAKE INFORMATION FOR MICHIGAN UTILITIES (PART I)

Plant name and location	Type of* structure	Distance off shore (in feet)	Water depth at intake location (in feet)	Distance of opening above lake bottom (in feet)	Spacing of crib intake bars (in inches)	Intake deicing provisions	Velocity at mouth of intake (fps)	Velocity at screens (fps)	Flow rate at pumps (cfs)
Bayside power station	Crib (2)	350	20	------	1 X 6	No	------	------	20
Traverse City		1700	40	6	0[1]	No	-------	------	11
Big Rock Nuclear plant Charlevoix	Crib	1500	30	10	18	No	1.5	2.0	116
Campbell Power Plant Port Sheldon	Shoreline	NA	NA	NA	NA	Yes	4.5	4.7	670
Cook Nuclear Plant Bridgeman	Crib (3)	2285	20	7	8 sq.	Yes	1.3	2.0	3700
Escanaba Generating Station Escanaba	Shoreline	NA	NA	NA	NA	Yes	------	------	56
Gladstone Generating Station Gladstone	Crib	550	43	3	6	No	------	------	8
Ludington Pumped Storage Power	Shoreline (2)	NA	NA	NA	NA	No	1.5	8.8[2]	66000
Plant Ludington		NA	NA	NA	NA	No	-------	3.0	102
Palisades Nuclear Plant South Haven	Crib	3200	40	10	11	No	0.5	0.7	833

---------- indicates data not supplied on questionnaire

NA = Not applicable

* Number in parenthesis denotes number of structures

[1] Crib is filled with rocks so no intake bars are necessary

[2] In pumping mode

LAKE MICHIGAN WATER INTAKE INFORMATION FOR MICHIGAN UTILITIES (PART II)

Plant name and location	Trash bar spacing (in inches)	Number of screens	Intake screen openings (in inches)	Method of cleaning screens[1]	Frequency of cleaning	Type and estimated weight of material removed	Intake fish screening devices present
Bayside power station Traverse City	-----	1	3/8 sq.	M	once/month	vegetation no estimate	1700' intake line has rock filled crib
Big Rock Nuclear plant Charlevoix	2 1/4	1	3/8 sq.	A	every 8 hrs.	vegetation, fish, no estimate	No
Campbell Power plant Port Sheldon	2 1/8	2	3/8 sq.	A	every 8 hrs.	vegetation, fish, no estimate	Bubble curtain
Cook Nuclear plant Bridgeman	2 5/8	14	3/8 sq.	A	--------	--------	No
Escanaba Generating Station Escanaba	3 3/4	2	--------	M	as needed	vegetation, debris, no estimate	No
Gladstone Generating Station Gladstone	NA	2	1/2 sq.	M	twice/year (spring & fall)	vegetation, fish, debris 10 to 20 lbs/cleaning	No
Ludington Pumped Storage Power plant Ludington	29 x 22	0	NA	NA	NA	NA	No
	NA[2]	3	1 X 4	M	no experience yet		
Palisades Nuclear plant South Haven	3 3/8	2	3/8 sq.	A	every 8 to 12 hours	fish, avg. 25 lbs./day	No

----------- indicates data not supplied on questionnaire

NA = Not applicable

[1] A = Automatically cleaned traveling screens actuated by timer, pressure differential or mannually
M = Manual removal and cleaning of screens

[2] The Ludington facility has a separate cooling water system for the pump/generator units

LAKE MICHIGAN WATER INTAKE INFORMATION FOR INDIANA UTILITIES (PART I)

Plant Name and Location	Type of Structure	Distance off shore (in feet)	Water depth at intake location (in feet)	Distance of opening above lake bottom (in feet)	Spacing of crib intake bars (in inches)	Intake deicing provisions	Velocity at mouth of intake (fps)	Velocity at screens (fps)	Flow rate at pumps (cfs)
Bailly Generating Station (coal)	Crib	1500	21	11	1	Yes	<1.0	------	762
Michigan City Generating Station, Michigan City	Shoreline	NA	NA	NA	NA	Yes	units 1 & 2 2.5 Unit 3 1.0	0.5	537
Dean H. Mitchell Generating Station, Gary	Shoreline	NA	NA	NA	5/16	Yes	1.5	0.8	964
State Line	Shoreline	NA	NA	NA	NA	Yes	units 1, 2,3 2.7 Unit 4 3.1	units 1, 2,3 2.7 Unit 4 3.1	895 Total

NA = Not applicable

------ indicates data not supplied on questionnaire

LAKE MICHIGAN WATER INTAKE INFORMATION FOR INDIANA UTILITIES (PART II)

Plant Name and Location	Trash bar spacing (in inches)	Number of screens	Intake screen openings (in inches)	Method of cleaning screens	Frequency of cleaning	Type and estimated weight of material removed	Intake fish screening devices present
Bailly Generating Station (coal)	2 5/8	4	3/16 sq.	A	once/8 hours	Debris, vegetation 25 to 400 pounds/day	None
Michigan City Generating Station, Michigan City	1	6	3/8 sq.	A	once/4 hours	Debris, vegetation 50 pounds/day	Air bubble screens and electric fish ticklers
Dean H. Mitchell Generating Station, Gary	2 7/8	8	3/16 X 22 1/2	A	once/ 8 hours	Debris, vegetation No estimate	Electric fish ticklers
State Line	4	10	3/8 X 1 1/2	A	----------	Debris, fish 30 pounds/day	None

---------- indicates data not supplied on questionnaire

LAKE MICHIGAN WATER INTAKE INFORMATION FOR ILLINOIS UTILITIES (PART I)

Plant name	Type of structure	Distance off shore (in feet)	Water depth at intake location (in feet)	Distance of opening above lake bottom (in feet)	Spacing of crib intake bars (in inches)	Intake deicing provisions	Velocity at mouth of intake (fps)	Velocity at screens (fps)	Flow rate at pumps (cfs)
Waukegan	Shoreline	NA	NA	NA	NA	Yes	0.5	0.8	1321
Zion *	Crib	2600	22	4'	none	Yes	1.0	2.0	3,409

NA = Not applicable
* = Questionnaire not returned. Data obtained in phone conversation with Mr. Pete Howe of Commonwealth Edison.

LAKE MICHIGAN WATER INTAKE INFORMATION FOR ILLINOIS UTILITIES (PART II)

Plant name	Trash bar spacing (in inches)	Number of screens	Intake screen openings (in inches)	Method of cleaning screens[1]	Frequency of cleaning	Type and estimated weight of material removed	Intake fish screening devices present
Waukegan	units 7 & 8, 2 inches units 5 & 6, 3 1/2 inches	14	unit 8, 1/4 sq. units 5, 6, & 7 3/8 sq.	A	once/4 hours	Fish, vegetation no estimate	fish net across shoreline
Zion	2	12	3/8 sq.	A	Not in operation		

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[1] A = Automatically cleaned traveling screens activated by timer, pressure differential or manually
M = Manual removal and cleaning of screens

LAKE MICHIGAN WATER INTAKE INFORMATION FOR WISCONSIN UTILITIES (PART I)

Plant name and location	Type of structure	Distance off shore (in feet)	Water depth at intake location (in feet)	Distance of opening above lake bottom (in feet)	Spacing of crib intake bars (in inches)	Intake deicing provisions	Velocity at mouth of intake (fps)	Velocity at screens (fps)	Flow rate at pumps (cfs)
Edgewater Unit 1&2	Crib	1500	18	6	12 sq.	Yes	0.8	0.5	294[1]
Sheboygan " 3&4	Crib	1420	18	6	12 sq.	Yes	2.5	0.8	
Kewaunee Nuclear Plant Kewaunee	Crib	1570	15	1	12 X 24	Yes	0.9	2.0	918
Lakeside Lakeside	Shoreline	NA	NA	NA	NA	Yes	1.4	1.1	1076
Manitowoc Manitowoc	Crib	2190	21	3	open	Yes	2.8	0.4	30
Oak Creek (South)	Shoreline	NA	NA	NA	NA	Yes	2.7	1.2	1765
Oak Creek (North)	Shoreline	NA	NA	NA	NA	Yes	0.8	0.8	980
Point Beach Point Beach	emergent crib	1750	22	5	2 X 1 3/16	Yes	0.9	0.9	1536
Port Washington Port Washington	Shoreline	NA	NA	NA	NA	No	2.8	1.7	1170
	Shoreline[2]	NA	NA	NA	NA	Yes[3]	2.8	----	-----
Pulliam Green Bay	South Shoreline	NA	NA	NA	NA	Yes	2.2	0.5[4]	810[4]
	North Shoreline	NA	NA	NA	NA	Yes	1.6		

--------- indicates data not supplied on questionnaire

NA = Not applicable

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[1] Total volume for both intakes

[2] Serves as an emergency intake only

[3] Condenser water discharge plume keeps emergency intake free of ice

[4] Intake waters are combined before reaching screens or pumps

LAKE MICHIGAN WATER INTAKE INFORMATION FOR WISCONSIN FACILITIES (PART II)

Plant name and location		Trash bar spacing (in inches)	Number of screens	Intake screen openings (in inches)	Method of cleaning screens [1]	Frequency of cleaning	Type and estimated weight of material removed	Intake fish screening devices present
Edgewater Generating Station, Sheboygan	Unit 1&2	NA	2	1/2 sq.	M	-----------	Debris, fish 60-80 lbs/day	No
	Unit 3&4	NA	3	1/2 sq.	A	----------	Debris, fish 60-80 lbs/day	No
Kewaunee Nuclear Plant Kewaunee		NA	4	3/8 sq.	A	no experience yet	debris, fish, no estimate	air bubble curtain at crib
Lakeside Plant Lakeside		7	8	3/8 sq.	A and M	as needed	vegetation, debris, fish no estimate	floating log baffle [2]
Manitowoc Public Utilities Manitowoc		NA	2	1/4 X 3/4	M	once/week	vegetation, debris, no estimate	No
Oak Creek (South)		3	5	5/16	A	-----------	vegetation, debris, fish	No
Oak Creek (North)		6 1/2 [3]	4	5/16	A	------------	vegetation, debris, fish	No
Point Beach Point Beach		2	8	3/8 sq.	A	once/12 hrs.	vegetation, fish, no estimate	No
Port Washington Port Washington		6 1/2	6	3/8 sq.	A	-------- ---	vegetation, debris, fish no estimate	Log skimmer
Pulliam Power Plant Green Bay South		8	14 [4]	3/8 sq.	A	once/8 hrs.	vegetation, debris, fish 0 - 2400 lbs/day	air bubble screen
North		5 3/4						

-------- indicates data not supplied on questionnaire

NA = Not applicable

[1] A = Automatically cleaned traveling screens actuated by timer, pressure differential or mannually
M = Manual removal and cleaning of screens

[2] Lakeside also has sheet piling below the lake surface to prevent soil from entering the intake. A rubble breakwater completely surrounding the intake, approximately 200 feet offshore, acts as a barrier against fish.

[3] Two sets are present spaced 18 inches apart.

[4] Intake waters are combined before reaching screens.